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SURGERY OF THE SPINE AND SPINAL CORD

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SURGERY OF THE SPINE AND SPINAL CORD

BY

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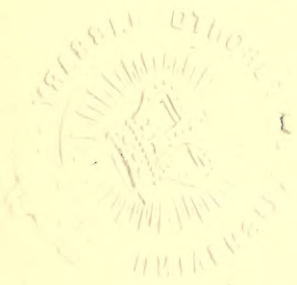

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To

W. W. F.

WHOSE CONSTANT INTEREST, SYMPATHY AND ENCOURAGEMENT
HAVE MADE MANY THINGS POSSIBLE

PREFACE

Apart from articles in the current journals, the literature of this country runs chiefly to the student text-book or to the expanded "systems" of medicine or surgery. It seems, to the author, therefore, that there is a place and a need for the more comprehensive and exhaustive treatment of medical subjects, such as is possible only in the monograph. In American literature the number of surgical monographs is very limited. Particularly when dealing with special fields of surgery is there a demand for the all-inclusive monographic consideration, and this is especially the case with those branches of surgery which have in recent years made rapid strides; it is eminently true of neurological surgery and more true of the surgery of the spine than of the brain. In surgery of the spine the indications for surgical intervention have increased rapidly in the last decade and a wide field of opportunity has been opened up.

In the preparation of this monograph on Surgery of the Spine and Spinal Cord, it has been my purpose to deal with the subject so comprehensively that it will not be necessary for the reader to consult collateral works. Thus there have been included in the contents chapters on the Anatomy of the Spine and Spinal Cord, on the Normal and Pathological Physiology of the Spinal Cord, on the Cerebrospinal Fluid and Its Relation to Spinal Diseases and on the Roentgen Examination of the Spine. These chapters, each written by a well-known authority, are so replete with information and so essential for reference, that they constitute an extremely valuable feature of the monograph.

With the same end in view, that is, of avoiding the necessity of consulting collateral works, the author has treated exhaustively, in addition to the surgical aspects of the diseases under consideration, the etiology, pathology and symptomatology. The scope of the book has been limited to those affections which belong properly to the domain of surgery, and to the exclusion of those affections, such as lateral curvature or tuberculous spondylitis, which belong to the domain of the orthopedist. Not only have there been included all lesions of the spine and spinal cord that at times demand surgical interference, but many procedures which require an intimate knowledge of the anatomy and physiology of the dural sac and its fluid content. There will be found chapters on Lumbar Puncture, Spinal Anesthesia and Intraspinal Therapy.

To the reader who seeks information on surgical diseases of the spine and spinal cord, whether it be in relation to the anatomy or physiology, the pathology or symptomatology, or the treatment, whether it pertain to

the vertebrae, spinal membranes, cord or cerebrospinal fluid, the author has endeavored to give a comprehensive presentation of the subject based upon his own personal experience, together with a critical analysis of the views of others. Only on the foundation of a thorough understanding of the knowledge so far at our command can we progress; it is in the hope that this book may help others to forge yet farther into the unknown and achieve yet greater benefit for mankind, that this broad survey of the subject has been undertaken.

The author acknowledges his deep gratitude to his colleagues, Dr. George A. Piersol, Dr. John A. Kolmer and Dr. Henry K. Pancoast, and to his collaborator, Dr. Alfred R. Allen, who contributed the introductory chapters. To Miss Ruth Guilder, for the literary research, to Dr. L. H. Landon for his assistance, and to Miss Christine Catrevas, for the proof-reading and preparation of the index, due acknowledgment is given.

CHARLES H. FRAZIER.

Philadelphia.

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SURGERY OF THE SPINE AND SPINAL CORD

CHAPTER I

ANATOMY OF THE SPINE AND SPINAL CORD

George A. Piersol

THE SPINE

The spine includes the segments of the vertebral column and the intervertebral disks uniting the individual vertebrae. It forms the fundamental part of the axial skeleton and extends from the skull above to the tip of the coccyx below and measures in length about 71 cm. (28 in.) in the adult male, being approximately 10 cm. (4 in.) shorter in the female. Individual variations in the length of the spine are inconsiderable, the differences in the height of individuals usually depending on the length of the lower limbs.

Preceded by a temporary axis, the notochord, the definite axis at first consists of a series of cartilaginous segments, which, although retained throughout life in some of the lower vertebrates, as in the cartilaginous fishes, is replaced in the higher animals by the bony segments constituting the vertebral column. These segments, the vertebrae, are bound together by dense, tough plates of fibrocartilage, the intervertebral disks, which, while firmly uniting the vertebrae to one another, confer considerable latitude of motion to the spine as a whole, and, at the same time, insure the necessary strength for support. In addition to supporting the weight of the portion of the body lying above the pelvis and giving attachments to many muscles, the spine encloses within the vertebral canal the spinal cord, giving efficient protection to this important part of the central nervous system.

The Vertebral Column

The vertebral column (*columna vertebralis*) of man consists of a series of thirty-three or thirty-four bony segments or vertebrae, certain of which during growth become fused and are then described as separate bones, although even in the adult condition evidences of the original seg-

ments of which they are composed may be readily detected. Therefore, the vertebrae are divided into *movable* and *fixed,* less appropriately called *true* and *false,* the latter terms manifestly suggesting erroneous notions as to the morphological value of these segments.

The vertebral column is divided into cervical, thoracic, lumbar, sacral and coccygeal vertebrae, in accordance with the regions in which they lie, of which the cervical number 7, the thoracic 12, the lumbar 5, the sacral 5 and the coccygeal 4, or 33 in all. Since, in the adult condition, the sacral and the coccygeal segments are more or less fused to form the sacrum and the coccyx, the movable segments, including the cervical, thoracic and lumbar, are often termed the *presacral vertebrae.*

FIG. 1.—AXIAL SKELETON OF MAN.

Features of Typical Vertebrae.—Although presenting many differences in the three regions, the presacral vertebrae possess certain features in common. Apart from the modifications dependent upon special uses, as at the upper end of the column, where the first and second vertebrae are modified to facilitate rotary motion, or in the thoracic region where additional articular facets exist for the ribs, the changes in the general features of the vertebrae are gradual and, for the most part, inconspicuous.

A typical vertebra, as represented by the sixth thoracic, consists of a robust mass of spongy bone, the *body* or *centrum,* of a general oval or cordiform outline, with flattened upper and lower surfaces; from the body dorsally springs the *vertebral arch,* that, with the body, completes the vertebral foramen surrounding the spinal cord. The body varies considerably in size according to the location of the vertebra examined, but is always greater in the transverse dimension than in the sagittal. Its ventral and lateral surfaces are slightly concave from above down-

ward, due to the overhanging thickened edges of the upper and lower surfaces, and are pierced by small nutrient foramina. In the thoracic region, the posterior part of the upper and lower margins of the body is interrupted by the demifacets for the articulations of the heads of

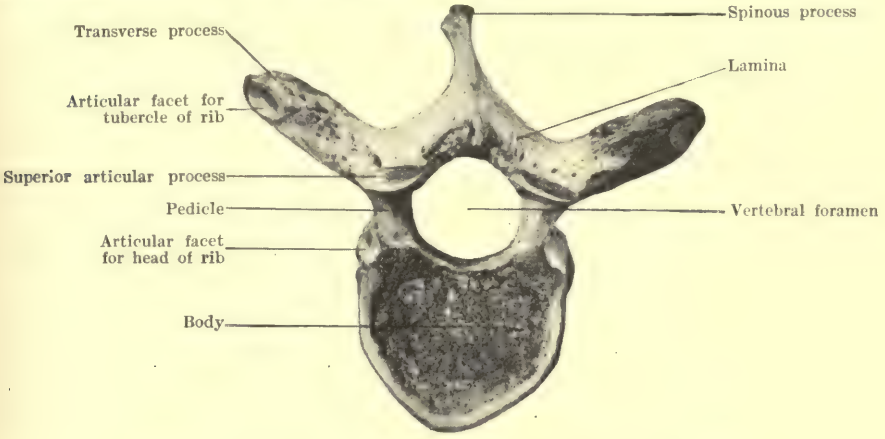

FIG. 2.—TYPICAL VERTEBRA, SIXTH THORACIC, FROM ABOVE.

the ribs, the lower facet usually being the smaller and more oblique. The dorsal surface of the body is flat from above downward, but concave from side to side, where it contributes to the wall of the vertebral canal. This surface is broken by the conspicuous openings of canals, which trans-

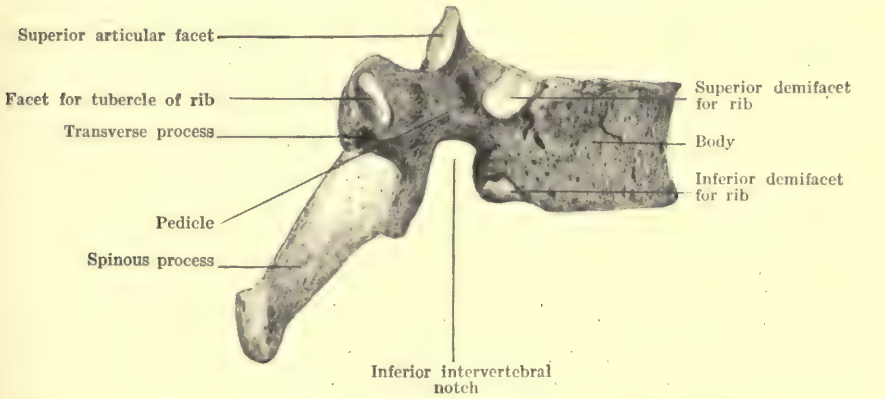

FIG. 3.—TYPICAL VERTEBRA, SIXTH THORACIC, FROM SIDE.

mit veins that largely drain the body. The upper and lower surfaces of the body are flattened, or slightly concave, and roughened for the attachment of the intervertebral disks. The margins of these surfaces are somewhat raised by a narrow zone of thickened bone.

The *vertebral arch* is formed by the union of the pedicles and laminae

and bears three muscular processes, the two transverse processes, stout lateral projections that spring from the junction of the pedicles and laminae, and the spinous process, which descends dorsally from the united laminae. The arch bears in addition two pairs of articular processes, the superior and the inferior, for the articulation of the preceding and succeeding vertebrae.

The *pedicles* or roots of the vertebral arch are laterally compressed bony bars, which arise, on either side, from the dorsolateral angle of the body and pass dorsally to the junction of the articular processes with the vertebral arch. The narrow upper and lower surfaces of the pedicles are smooth and rounded; the vertical medial surface is also smooth, while the lateral surface is rough except in the cervical region, where this surface assists in bounding the transverse foramen and is smooth. Since the vertical dimension of the pedicles is only about one-half of that of the body, it follows that deep offsets lie behind the body; these are the *intervertebral notches* (*incisurae intervertebrales*). Of these, two on each side are described, an upper and a lower, of which the lower is much the deeper, except in the cervical region, where the notches are of almost equal depth. When the vertebrae are in articulation, the notches are converted into rounded apertures, the *intervertebral foramina,* which communicate with the vertebral canal and transmit the spinal nerves and accompanying blood vessels. They are bounded in front by the body, above and below by the rounded edges of the pedicles, and behind by the projections bearing the articular processes.

The *laminae* are the two flattened plates that posteriorly unite the pedicles, thus completing the vertebral foramen, and are continuous dorsally with the root of the spinous process. They are irregularly quadrilateral in form, with ventral surface and margins roughened for the attachment of the ligamenta flava, which bind together the laminae of the adjacent vertebrae. They are broadest in the thoracic region and narrowest in the cervical; by their apposition with those of adjoining segments, they almost completely close the vertebral canal, of which they contribute the posterior wall. The *vertebral foramen,* enclosed by the body and the vertebral arch, varies in shape and size in the different regions. It is of large size and of triangular or cordiform outline in the cervical spine, smaller and approximately circular in the thoracic, and again large and triangular in the lumbar region. By the apposition of the vertebrae and the intervertebral disks and the ligamentous structures uniting the individual segments, the vertebral foramina are converted into the continuous vertebral canal, which extends from the foramen magnum of the skull above to the lower end of the sacrum below.

The *transverse processes* are two stout projections which arise from the vertebral arch at the junction of the pedicles and laminae. They are directed laterally and, for the most part, somewhat backward and serve

as levers for the attachment of muscles. Those belonging to the cervical vertebrae are composite and pierced by a large aperture, the *transverse foramen* (*foramen transversarium*), which gives passage to the vertebral artery and vein and plexus of sympathetic nerves, and is the most characteristic feature of these vertebrae (Fig. 4). The so-called transverse process consists of two parts: a robust bar lying behind the foramen and

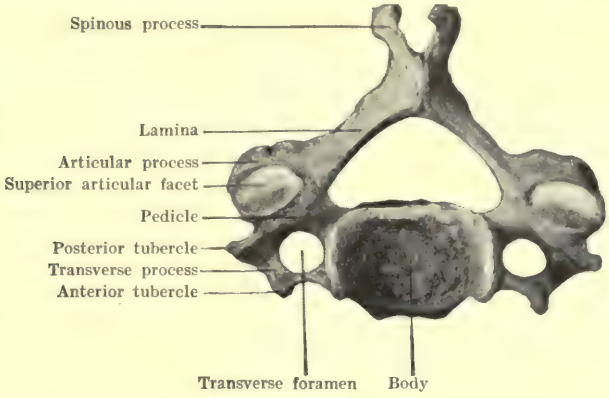

FIG. 4.—FOURTH CERVICAL VERTEBRA, FROM ABOVE.

a slender one in front. The posterior bar is the true transverse process; the anterior bar is regarded as a costal element, since, in exceptional cases, it may ossify from an independent center and remain separate as a cervical rib. The transverse processes of the thoracic vertebrae, except those of the eleventh and twelfth, are provided with articular facets, on the anterior surface near the tip, against which the facets on the tuberosi-

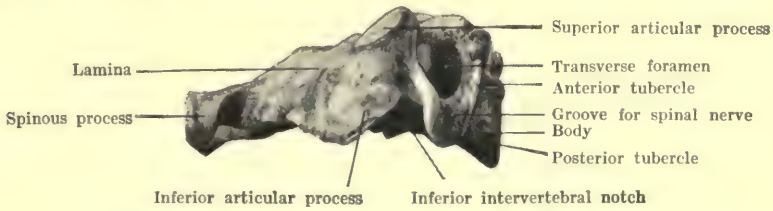

FIG. 5.—FOURTH CERVICAL VERTEBRA, FROM SIDE.

ties of the ribs play. The so-called transverse processes of the lumbar vertebrae (Fig. 6) are homologous with ribs fused with the vertebral arch; hence, they are equivalent to costal elements. The true transverse processes are represented by the *accessory processes,* mostly small and insignificant tubercles, that lie on the posterior aspect of the conventional transverse processes.

The *spinous process* is unpaired and median and springs from a broad triangular base that is continuous with the laminae at their point of

union. While directed posteriorly, the spinous processes vary in length and obliquity in different parts of the column. Those in the cervical

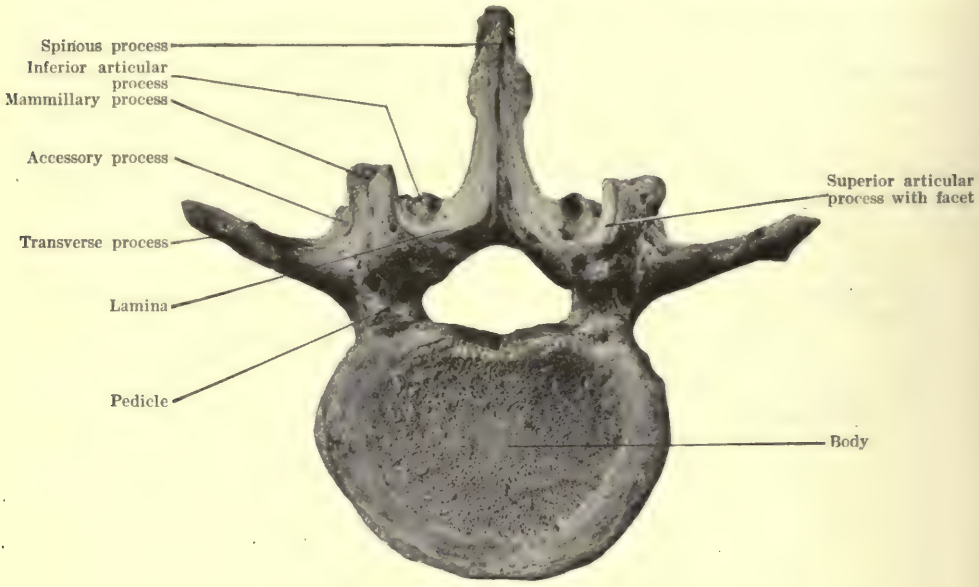

FIG. 6.—THIRD LUMBAR VERTEBRA, FROM ABOVE.

region are mostly short, horizontal and bifid; in the upper thoracic region they are long and descend with increasing obliquity, while below the seventh thoracic vertebra they diminish in length and obliquity, gradually

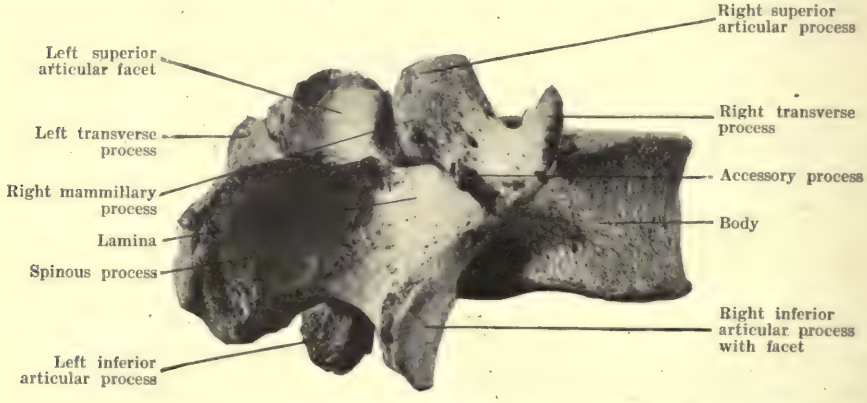

FIG. 7.—THIRD LUMBAR VERTEBRA; OBLIQUE SIDE VIEW.

assuming the robust character and horizontal direction which distinguish the processes of the lumbar vertebrae.

The *articular processes,* or *zygapophyses,* are four in number and dis-

posed in pairs, the superior and the inferior, and project from the vertebral arch where the pedicles and laminae meet. The upper ones are more closely related to the pedicles and the lower ones to the laminae. While in general the articular facets of the upper pair face backward and upward, those of the lower pair look forward and downward. There are, however, great differences in the direction of the articular planes of the three groups of presacral vertebrae, and by these variations the different kinds of motion permitted between the individual vertebrae are largely determined.

Peculiar Vertebrae

The Atlas.—The first cervical vertebra, the atlas, is distinguished by the absence of the body and the spinous process, and consists of two lateral masses connected by an anterior and a posterior arch.

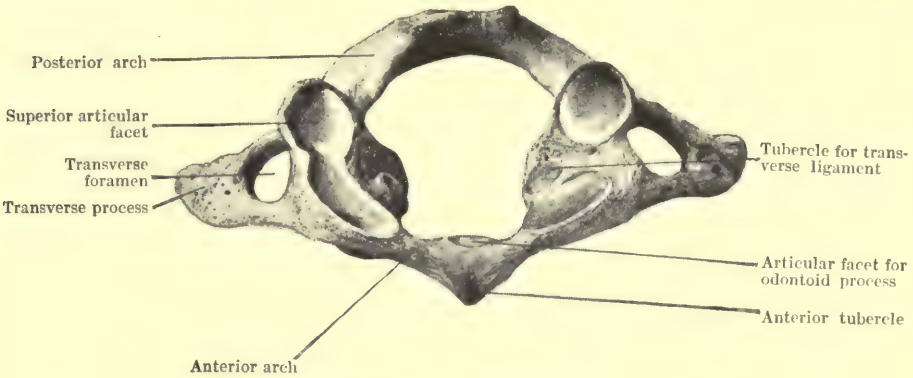

FIG. 8.—ATLAS, FROM ABOVE.

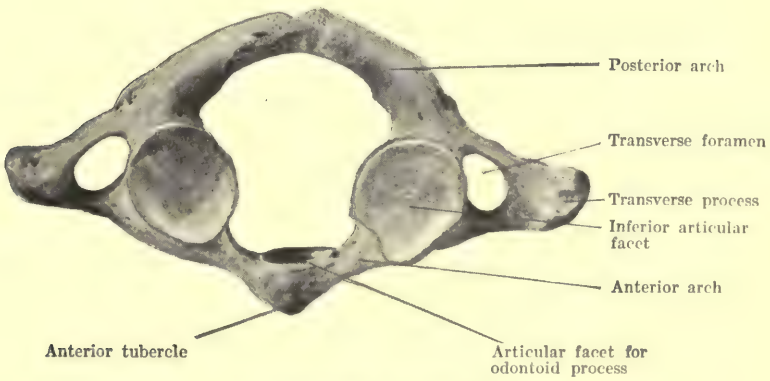

FIG. 9.—ATLAS, FROM BELOW.

Each *lateral mass* is a robust, irregularly bony condensation, which in front is prolonged medially into the anterior arch, behind joins the

posterior arch, and at the sides gives attachment to the transverse process. Medially, the forepart of the lateral mass bears a small but distinct tubercle for the attachment of the transverse ligament, which holds in place the odontoid process of the axis and prevents its backward displacement. The elongated superior articular facet is frequently notched and sometimes completely separated into two parts. The oblique lower surface of the lateral mass bears the inferior articular facet, which is irregularly circular and slightly concave from side to side.

The *anterior arch* is the weakly curved bar connecting the anteromedial parts of the two lateral masses. It is compressed from before backward, but on its anterior aspect presents a medial rounded projection, the *anterior tubercle.* Opposite this tubercle the posterior surface of the arch presents a circular articular facet (*fovea dentis*) for the odontoid process of the axis.

The *posterior arch,* much stouter than the anterior, springs from the dorsal aspect of the lateral masses, about midway between their upper and lower surfaces. Its superior surface, next to the lateral mass, is modeled, on either side, by a wide groove, which curves around the posterior part of the overhanging superior articular facet and leads to the transverse foramen. This groove is occupied by the vertebral artery in its passage from the foramen in the transverse process to the foramen magnum, and by the suboccipital nerve. The transverse process springs from the lateral surface of the lateral mass and extends outward farther than in any other cervical vertebra, with the possible exception of the seventh. The extremities of the two limbs of the process are fused into a broad flattened mass, slanting downward and forward. The roughly oval or fiddle-shaped space enclosed by the two arches and the lateral masses is subdivided by the transverse ligament into two compartments: the smaller anterior one lodges the odontoid process of the axis, while the much larger posterior compartment corresponds to the vertebral foramen.

The Axis.—The axis (*epistropheus*), the second cervical vertebra, is distinguished by the conspicuous odontoid process that projects upward from the body.

The *odontoid process* (*dens*) represents the body of the atlas, fused with that of the axis. It is a stout bony cylinder, somewhat compressed laterally, which above ends, after a slight expansion, in a blunted point. At the sides the apex bears two small tubercles, to which, and to the roughened tip, the alar and apical ligaments are respectively attached. In front, the odontoid process is provided with a convex oval *articular facet,* which plays against the flatter facet on the anterior arch of the atlas and marks the upper limit of a slight constriction. Behind and at a lower level, the process is modeled by a second facet, for the cartilage-covered opposed surface of the transverse ligament of the atlas.

The anterior surface, at its lower part, presents a triangular elevation, which is prolonged upward as far as the root of the odontoid process. At the sides, the body widens in its ascent to fuse with the transverse process and pedicle to form the broad mass bearing the superior articular facet. The inferior surface of the superior articular process is deeply grooved by the transverse foramen, which here turns laterally, so that its upper

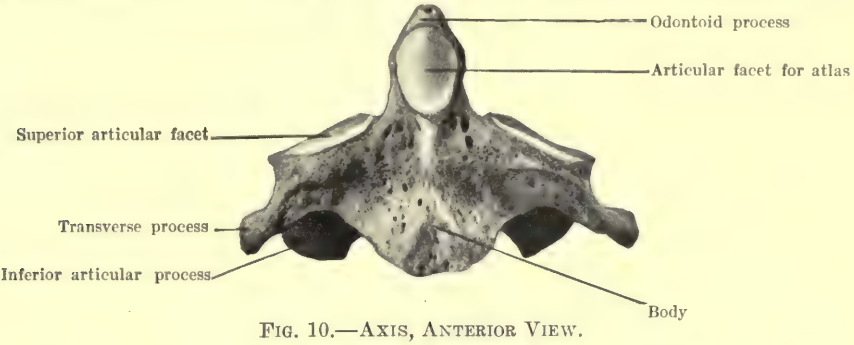

FIG. 10.—AXIS, ANTERIOR VIEW.

aperture is directed obliquely outward and partly masked by the overhanging articular facet.

The intervertebral notch is well marked and bounded behind by the inferior articular process. This process bears the obliquely placed inferior facet, which is directed downward, forward and somewhat outward, to accord with the upper facet of the next vertebra below.

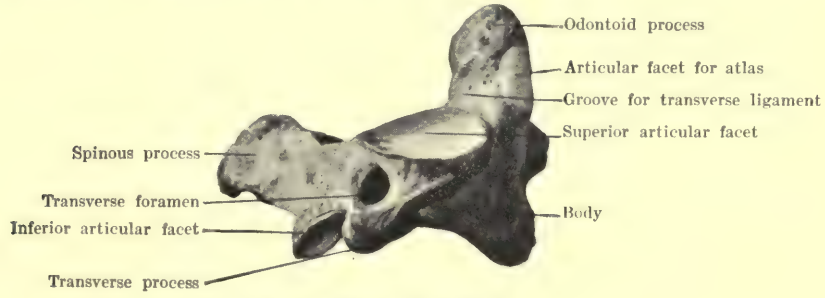

FIG. 11.—AXIS, FROM SIDE.

The Seventh Cervical Vertebra.—This segment is often called the *vertebra prominens* in recognition of the prominent projection of its spinous process. The latter is a third longer than the process above and directed more horizontally than the process below, hence its tip, which ends in a single slightly notched tubercle, is to some degree isolated and produces a corresponding surface projection at the root of the neck. The body is transversely expanded, which, in conjunction with the great length of the transverse processes, gives to the vertebra a much greater breadth than that of the preceding segment.

Peculiar Thoracic Vertebrae.—The peculiar thoracic vertebrae, the first, tenth, eleventh and twelfth, sometimes also the ninth, are distinguished from the other members of this group chiefly by the modifications in their articular relations with the ribs.

FIG. 12.—PECULIAR THORACIC VERTEBRAE: FIRST, NINTH, TENTH, ELEVENTH AND TWELFTH.

The First Thoracic Vertebra.—The first thoracic vertebra resembles the last cervical in the general shape and modeling of the upper surface of its body, and in the length and direction of its spinous process. The body bears on its posterolateral margin, on either side, a circular

facet for the head of the first rib above, and a smaller demifacet below for the upper articular surface of the second rib. The transverse processes are long and carry the facet for the tuberosity of the first rib.

The Tenth Thoracic Vertebra.—This vertebra has only one facet, on either side, for the head of the tenth rib. It lies well on the pedicle and may be complete, when the lower facet on the ninth vertebra is absent, as it occasionally is. When the last named surface is present, the demifacet is small and insignificant, although taking part in supporting the rib. The facet on the transverse process is usually small and may be absent.

The Eleventh Thoracic Vertebra.—The eleventh thoracic vertebra has a single complete facet, on either side, for the head of the eleventh rib. It lies entirely in relation with the lateral surface of the pedicle. The transverse processes are short and stunted and are without rib-facets.

The Twelfth Thoracic Vertebra.—The twelfth thoracic vertebra resembles the adjoining lumbar segment in its general appearance. The single facet for the twelfth rib lies on the lower part of the lateral surface of the pedicle, on either side. The transverse processes are short and stunted and without rib-facets. Their outer surface is rough and presents three projections, the superior, inferior and lateral tubercles, which foreshadow respectively the mammillary, accessory and transverse processes of the lumbar vertebrae. The inferior articular processes differ from the superior in being directed outward, instead of backward, in correspondence with the disposition of the superior facets on the first lumbar vertebra.

The Fifth Lumbar Vertebra.—The fifth lumbar vertebra is distinguished by the large size and wedgelike form of its body, the thickness of which is markedly less behind than at the anterior margin. In consequence, its lower border takes part in producing the sacrovertebral angle. While the upper surface of the body is faintly heart-shaped in outline, to correspond with the body of the vertebra above, the inferior surface is of transversely elongated form and resembles the opposed surface of the sacrum.

The Sacrum

The five sacral segments representing the modified vertebrae of which the sacrum is composed remain discrete and separated by thin intervertebral disks until about the fifteenth year. During the period from the fifteenth to the twentieth year, they undergo fusion, but more or less distinct remains of the lines of union are often present at twenty-five, while bony ridges subsequently mark off the original segments. In addition to union, the chief modification that the sacral vertebrae undergo is the fusion of the transverse processes and rib elements to form the lateral

masses. The sacrum is of a general triangular form, with the expanded base above and the apex below.

The *anterior surface* is concave, slightly from side to side and more markedly from above downward, the curve, in the female, becoming more acute below the third segment. The central part of the anterior surface is formed by the bodies of the sacral vertebrae, the lines of union of the bodies being indicated by transverse ridges. Laterally, these ridges disappear, on either side, at the medial borders of the large anterior sacral foramina, although they are continued on the sides and posterior surface

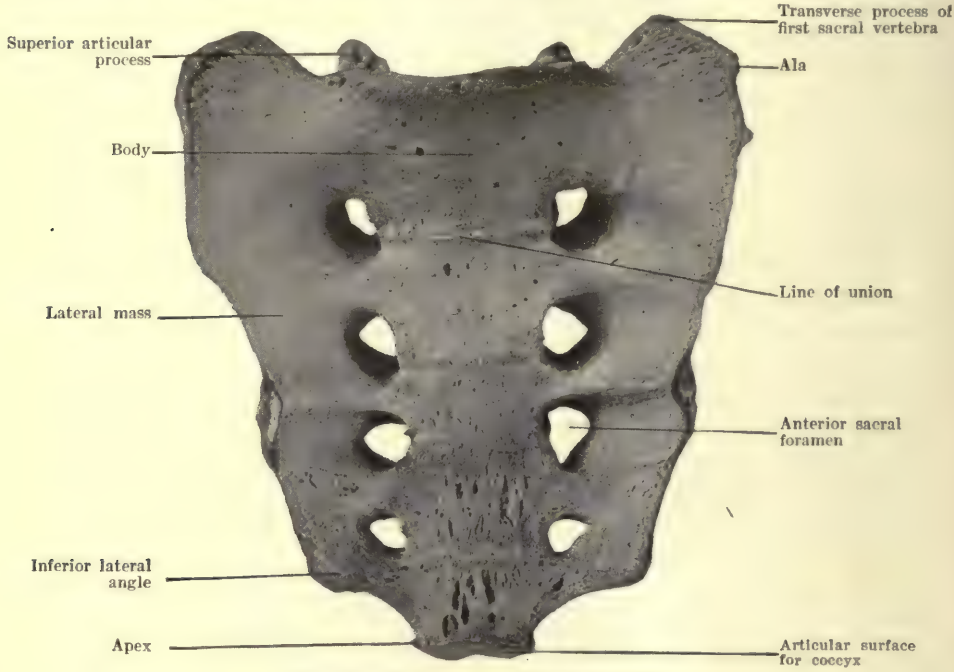

FIG. 13.—SACRUM, ANTERIOR SURFACE.

of the fused bodies. The bodies are prolonged laterally, on either side, into robust bony bars, five in number, that contribute the upper and lower boundaries of the foramina. Beyond these openings the bony bars broaden out and fuse into the *lateral masses,* which complete the boundaries of the foramina by supplying the outer grooved walls. The *anterior sacral foramina,* four in number, usually decrease in size from above downward, but not infrequently the second and third openings are larger than the first, the increase being due chiefly to the outward sloping of their grooved lateral walls. The apertures transmit the large anterior divisions of the sacral nerves, which also occupy the grooves leading outward from the foramina. The lateral margins of the anterior surface are not straight but sinuous, since the sacrum widens out opposite the

third vertebra and then rapidly narrows. Just before curving medially to join the apex, the margin is prolonged into the *inferior lateral angle.*

The *posterior surface,* rough and convex from above downward, is modeled in the midline by a series of projections, more or less fused into a common ridge, the *crista sacralis media.* These projections, usually four in number, but often only three, represent the spinous processes of the sacral vertebrae, the upper two retaining in a measure the features of spinous processes, while the lower ones are rudimentary and little more than irregular tubercles. On either side of the median crest lies

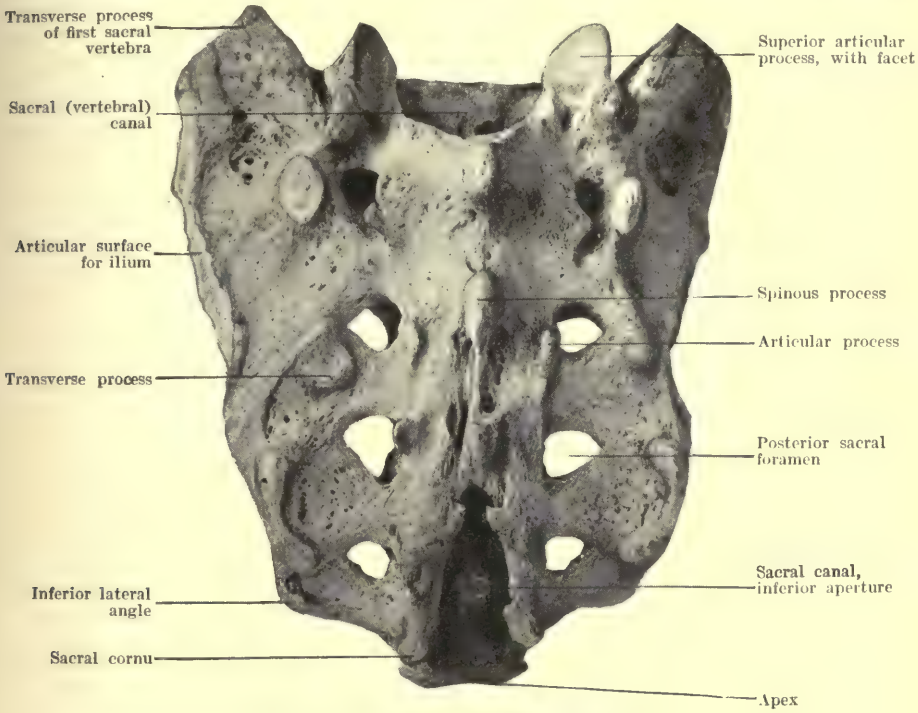

FIG. 14.—SACRUM, POSTERIOR SURFACE.

the *sacral groove,* the floor of which is composed of the fused laminae of the sacral vertebrae. The groove is limited laterally by a second ridge and series of low elevations, the representatives of the articular processes. Below, the interrupted ridges thus formed, the *cristae sacrales articulares,* become much more distinct, and are prolonged into diverging prominent processes, the *sacral cornua,* which bind the incompletely closed vertebral canal and bear the inferior articular facets of the fifth sacral vertebra, for articulation with the coccyx. The groove beneath the overhanging cornu, corresponding to an intervertebral notch, by the apposition of the coccygeal cornu is converted into an intervertebral foramen, through which the fifth sacral nerve escapes.

Lateral to the rudimentary articular processes, on either side, are seen the *posterior sacral foramina.* These apertures, four in number, are much smaller and less regular than the anterior foramina and are bounded by thin sharp edges. They transmit the posterior divisions of the sacral nerves, the third foramina being the largest. The anterior and posterior sacral foramina lie opposite one another and are the apertures of wide canals, whose length corresponds to the thickness of the sacrum. While the lateral walls of these canals are unbroken, the median walls are pierced by the progressively diminishing openings of the intervertebral foramina, the latter, in conjunction with the sacral foramina, forming a series of ➢-like passages, transmitting the trunks and divisions of the sacral nerves. The posterior surface of the lateral mass is roughened by a third series of uncertain and irregular elevations, fused into a ridge, the *lateral sacral crest,* lying to the outer side of the sacral foramina. These elevations,

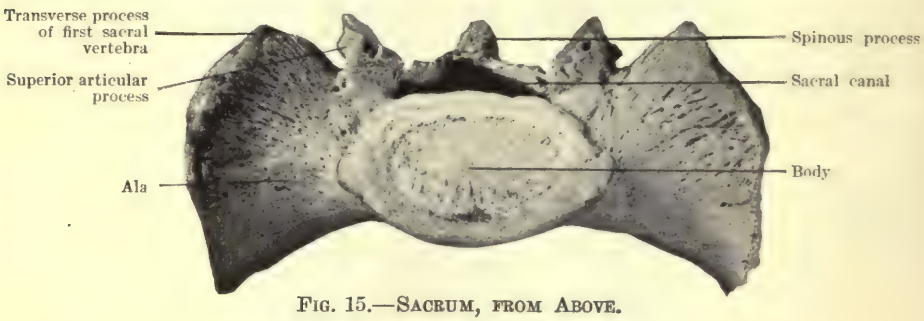

FIG. 15.—SACRUM, FROM ABOVE.

four in number and best marked in the lower part of the series, are homologous with the true transverse processes of the lumbar vertebrae.

The *base* of the sacrum, the expanded upper surface of the bone, includes the medially situated body and the lateral fan-shaped expansions, the *alae.* The superior surface of the body is oval and articulates with the fifth lumbar vertebra through the medium of an intervertebral disk. The sharp anterior margin of the body overhangs the concavity of the posterior pelvic wall, the projection constituting the *promontory* of the sacrum. Behind the body lies the triangular sacral canal, compressed from before backward and enclosed by the short pedicles and the fused sloping laminae. The canal diminishes in size in its descent and, at the level of the fourth, or often third, sacral segment, loses its posterior wall in consequence of the failure of the laminae to unite. The winglike mass, the *ala sacralis,* which, on either side, broadens out from the sides of the body, constitutes the upper surface of the lateral mass. The posterior border of the ala is interrupted by a narrow but deep incision, which separates the conspicuous superior articular process from a prominent tubercle. Development of the lateral masses shows that these

parts of the sacrum represent fusions of the pedicles, transverse processes and costal elements.

The *lateral surface* of the sacrum is triangular, broad above and rapidly tapering to a thin edge below the level of the third segment. The upper and main part of this surface is subdivided into an anterior articular and a posterior ligamentous area. The anterior area is elongated and somewhat sigmoid, or, as usually described, ear-shaped in outline. This, the *iliac articular surface,* is the sacral contribution to the joint

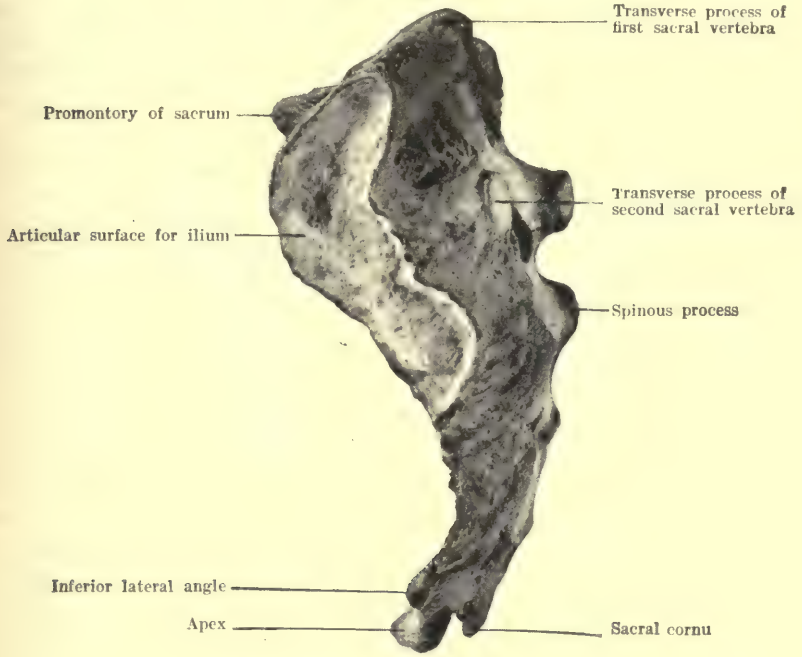

FIG. 16.—SACRUM, LATERAL ASPECT.

between the spine and the innominate bone, and is directed outward, its lower raised lip usually falling on a level with the middle of the third sacral vertebra. Behind the articular surface, the bone is roughened and pitted for the attachment of the powerful sacro-iliac ligaments.

The *apex* of the sacrum, its lower end, is formed by the inferior surface of the small body of the fifth sacral vertebra, which articulates with the coccyx through the medium of an intervertebral disk.

Differences Depending upon Sex.—These differences are fairly definite. The female sacrum is relatively broader than that of the male and presents a curve less regular than in the opposite sex. In the male, the concavity is absolutely deeper and more uniform; in the female, on the contrary, the anterior surface is almost flat from the promontory to

the middle of the third segment, from which level to the apex the curve becomes much more acute.

The Coccyx

This bone (*os coccygis*) is composed of four, sometimes five and more rarely three, rudimentary vertebrae, in which little else than the body is distinguishable. After middle life all the segments are commonly fused, but not infrequently the first coccygeal vertebra remains separate, fusing neither with the second nor with the sacrum.

The *first* coccygeal vertebra consists principally of the body, from which extend laterally rudimentary transverse processes. The upper surface of the body is compressed from before backward and is devoted

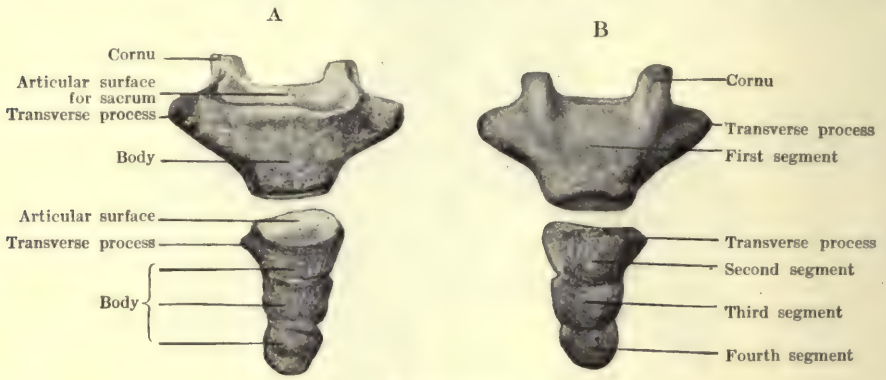

FIG. 17.—COCCYX.
A, Anterior surface; B, posterior surface.

almost entirely to the narrow oval facet for articulation with the apex of the sacrum, an intervertebral disk intervening so long as fusion does not occur. The converging sides slope downward to embrace the much smaller lower articular facet for the second segment, which may be retained throughout life, but which ordinarily is obliterated by bony union. Posteriorly, where the root of the transverse process joins the body, two conspicuous processes, the *cornua coccygea,* extend upward for a variable distance. These projections are in series with the articular processes of the sacrum, and, unless stunted, meet the lowest sacral processes to complete the boundaries of the fifth intervertebral foramen, the last of these apertures.

The *second* coccygeal vertebra consists of a triangular body, with feebly marked transverse processes and, perhaps, suggestions of a vertebral arch.

The *third* and *fourth* coccygeal vertebrae are merely compressed oval bony nodules, separated on the surface by grooves, indicating the lines along which the original segments have fused. Occasionally the last seg-

ment remains separate, a condition occurring more often in the female than in the male.

The Vertebral Column as a Whole

Bearing in mind the fundamental purpose of the vertebral column in man—to support the head, trunk and upper extremities and to transmit the weight of these parts of the body to the pelvis and lower limb—it is manifest that the bodies of the vertebrae, together with the intervertebral fibrocartilages, are the chief factors in fulfilling this function. Incidentally, this supporting pillar affords protection to the spinal cord by enclosing it within the vertebral canal.

While collectively the bodies of the movable vertebrae form a pyramidal series, on inspection from in front, the bodies are seen to increase in breadth from the axis to the first thoracic vertebra, then to decrease slightly to the fourth thoracic, and thence to broaden gradually to the sacrum. The main pyramid, therefore, is composed of three subsidiary ones, of which the second has its base directed upward. From the base of the sacrum the bodies of the fixed vertebrae rapidly narrow to the nodules of the coccyx. The bodies of the third, fourth and fifth thoracic vertebrae frequently exhibit a flattening on the left side. The flattening is most pronounced at the fifth vertebra, below which it fades away towards the midline. This indentation, *the impressio aortica,* is associated with a slight lateral curvature of the column to the right. The impression itself is attributable to the pressure induced by the upper part of the thoracic aorta, while the deflection of the spine may be due to the greater use of the right upper extremity, favored by the aortic impression.

Viewed from the side, the height of the bodies increases gradually from above downward as far as the sacrum, with, however, a tendency to a rather sudden augmentation at the junction of the cervical and thoracic and of the thoracic and lumbar regions.

When seen in profile, assuming that the posture is erect and the head so placed that the visual axes are directed horizontally, the spine presents four curves in the anteroposterior direction. From the regions in which they occur, they are called the *cervical,* the *thoracic,* the *lumbar* and the *sacral.* Two of these, the thoracic and the sacral, have their convexity directed backward and, therefore, add to the capacity of the thoracic and pelvic cavities. They exist before birth and are *primary curves.* The other two, the cervical and the lumbar, have their convexity directed forward and appear after birth only when the erect posture is assumed. These are *secondary* or *compensatory curves.*

The primary curves are developed early in fetal life, but at birth the spine presents only a general curvature, with the concavity directed for-

ward, in which the pelvic and thoracic parts are only slightly differentiated from each other. Of the secondary curves, the cervical appears first, as the infant acquires strength to hold up its head, while the lumbar curve does not appear until between one and two years, when the child learns to walk. With the exception of the lumbosacral junction, where the change to the backward bend of the sacrum is abrupt and marked by the *sacrovertebral angle,* the transition of one curve to the other is gradual. As seen in sagittal sections of frozen male bodies, the summit of the cervical curve falls at the level of the fourth vertebra; the concavity of the thoracic curve is deepest at the seventh or eighth vertebra; the summit of the lumbar curve corresponds with the fourth vertebra. These curves obviously undergo temporary changes during movements of the spine. They also gradually alter during the period of growth, and become, in a sense, consolidated only after middle life—in the cervical region, perhaps never. The advantages of a spine possessing the presacral curves over a perfectly straight column are manifestly greater elasticity and protection from injury by minimizing the effects of shocks and blows.

The curves depend upon the form of the bodies and of the intervertebral disks. The cervical curve depends chiefly upon the greater thickness of the disks in front than behind, since the bodies of the vertebrae are about equal in thickness front and back, or, indeed, may be lower in front. The thoracic curve owes its production to the form of the bodies, as well as to that of the disks, since both are distinctly lower in front than behind. The lumbar curve is a conspicuous example of the influence of the form of the intervertebral disks, all of which are markedly wedge-shaped, the base of the wedge being anterior. On the contrary, the bodies of the upper two vertebrae are often lower in front than behind, and only the fifth vertebra, and in a lesser degree the fourth and third, exhibits a pronounced difference in favor of the height in front. The pelvic curve, dependent on the anterior surface of the sacrum and coccyx, is not uniform, but sharpest in its lower part, especially in women.

At first the promontory, which marks the bend between the lumbar and sacral curves, is not formed by the first sacral segment but by the second; later, during the latter half of fetal life, the promontory migrates cranially one vertebra and assumes its permanent position at the superior border of the first sacral segment. Individual variations in the presacral curves are influenced by the angle made by the plane of the pelvic inlet with the horizontal plane; the greater this angle, the more marked will be the lumbar and sacral curves, corresponding with the regions permitting the greatest amount of movement.

The transverse processes of the atlas are widely spreading and prominent, being in a measure isolated by the failure of the succeeding processes to reach the lateral limits of the atlas. While very gradually increasing their spread, the difference is so slight that, from the second to the sixth

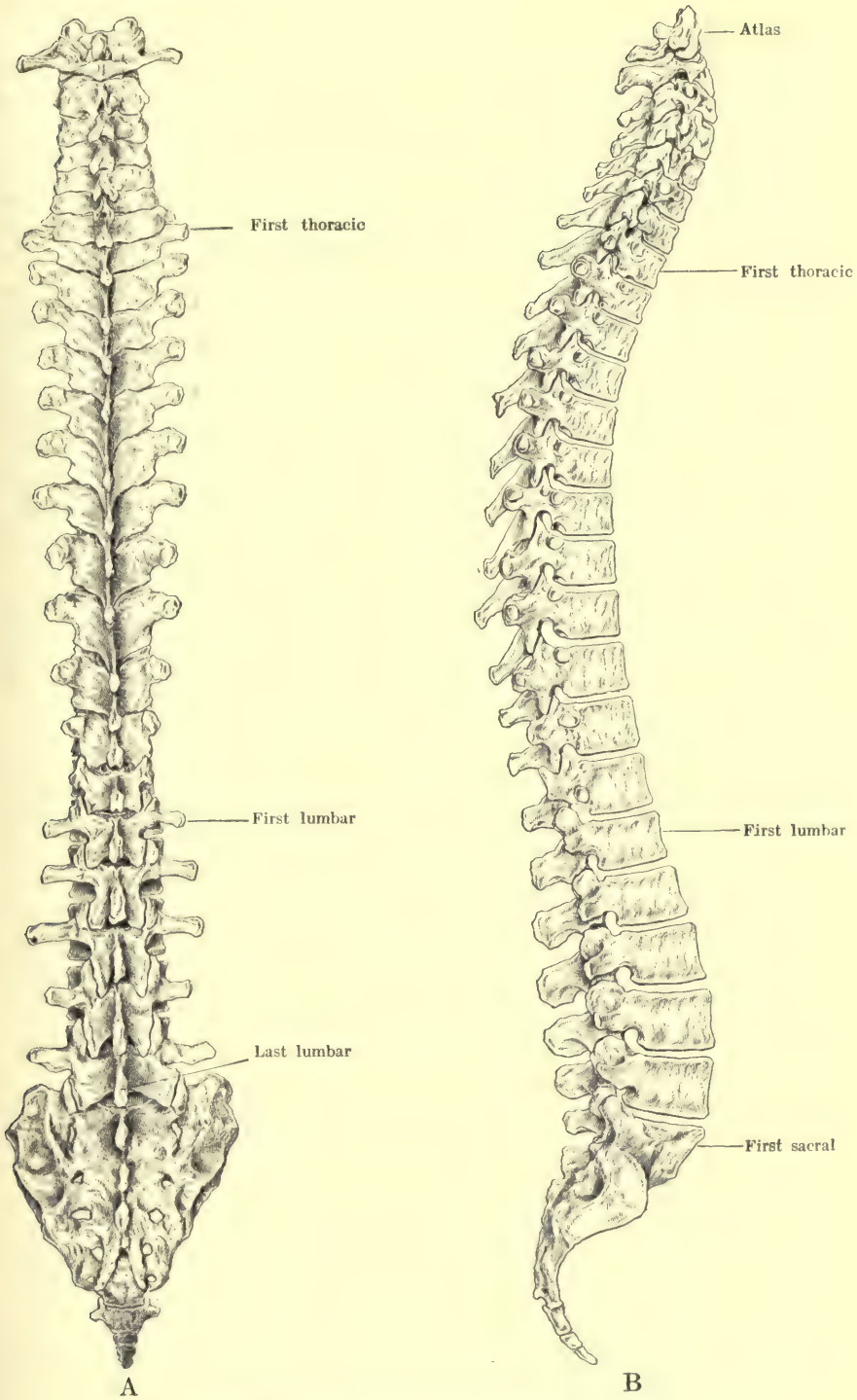

FIG. 18.—BONY SPINE OR VERTEBRAL COLUMN.
A, From behind; B, from side.

vertebra, the tips of the transverse processes are about equally extended. At the seventh vertebra, however, a sudden expansion occurs, so that the transverse processes fall nearly in line with those of the atlas and of the first thoracic vertebra. The anterior tubercles of the transverse processes of the sixth cervical vertebra are very prominent, forming what has been called the tubercles of Chassaignac, against which the common carotid arteries may be compressed.

The spread of the transverse processes of the thoracic region decreases from the first to the third vertebra, remains about constant to the ninth, and then diminishes to the twelfth, where the processes are rudimentary tubercles. The lumbar transverse processes, widely outstanding and prominent, increase in length to the third ones, which are usually the longest of the entire series, the processes of the fourth being commonly shorter than either those of the third or the fifth vertebra. The backward inclination of the transverse processes of the thoracic region, seen only in man, is associated with the erect posture and bringing a part of the weight borne by the spine behind the column and the axis of gravity.

Within the presacral spine the intervertebral foramina increase in size from above downward, those in the lumbar region being the largest. Within the sacrum they decrease in their descent and open on the anterior and posterior surfaces through the corresponding sacral foramina. With the exception of the first and second pairs, which pass behind the articular processes, all the cervical nerves pass between the transverse and articular processes in their escape through the intervertebral foramina. On reaching the thoracic region, however, the nerves pass anterior to both these processes, a similar relation existing in the lumbar spine.

Viewed from behind, the articulated column presents the interrupted median ridge, formed by the backwardly projecting spinous processes. At the sides of this ridge extend deep furrows, the *vertebral grooves,* bounded laterally by the transverse processes in the cervical and thoracic regions, and by the mammillary processes in the lumbar. The floor of each groove, in its upper part, is formed by the dorsal surface of the laminae, while lower the laminae are assisted by the articular processes. These gutters are filled by the longitudinal series of muscles, which support and move the spine. The spaces between the superimposed laminae, in the natural condition closed by the ligamenta flava, form a series of intervals that vary in height in the different regions. Thus, in the cervical and upper two-thirds of the thoracic spine, they are mere narrow clefts, but in the lower third of the thoracic and lumbar regions they are spaces of increasing and considerable size, those between the lower lumbar vertebrae being arched spaces about 1.5 cm. in height. Advantage is taken of the relatively large size of the lumbar intervals in performing spinal puncture, the needle being introduced usually just above or below, and to the side of the fourth lumbar spine, with an inclination upward and inward. A

line joining the highest points of the two iliac crests passes through the fourth lumbar spine.

Owing to the variation in the length and direction of the spinous processes, a line connecting their tips repeats only in a general way the curves of the spine. With the exception of the spinous process of the atlas, which is projecting, the spines of the succeeding cervical vertebrae are short and deeply placed, until the seventh vertebra is reached. This, the *vertebra prominens,* possesses a long horizontally projecting spine, readily felt, and is the beginning of a series of subcutaneous elevations that, below the second thoracic vertebra, are easily located in the median spinal furrow, between the longitudinal ridges of muscles, as low as the third sacral spine. Although directed with a general downward slope as far as the lower limit of the thoracic region, the inclination of the spinous processes varies in different parts of the column. The seventh cervical spine interrupts the downward direction of the processes above by projecting more horizontally than either of its neighbors. With the first thoracic vertebra begins a progressively increasing obliquity, the maximum descent being exhibited usually by the seventh thoracic spine. Below this point the obliquity of the spine diminishes, the lumbar spinous processes having an almost horizontal, or indeed, as in the case of the lower vertebrae, a slight upward inclination.

Dimensions.—The average length of the spine, the articulated vertebrae being connected by the intervertebral disks and the measurements being taken along the anterior surface of the column, is about 71 cm., or 28 in., in the male, and about 61 cm., or 24 in., in the female. Of the entire length of the spine, the cervical region contributes about one-sixth (16 per cent), the thoracic region something more than one-third (38 per cent), the lumbar region about one-quarter (24.5 per cent), the sacrum about one-sixth (17 per cent) and the coccyx nearly one-twentieth (4.5 per cent). Of the presacral column, the cervical region forms about one-fifth (20.5 per cent), the thoracic region almost one-half (49 per cent), and the lumbar region not quite one-third (30.5 per cent).

Architecture of the Vertebrae

As seen in the adult vertebrae, the osseous tissue is everywhere disposed as a thin shell of compact bone, enclosing a central mass of cancellated tissue. The latter, within the centrum and seen in frontal section, is arranged as vertical plates, to resist pressure, intersected and bound together by horizontal ones to form a fairly regular meshwork. At the periphery of the body, the vertical plates are somewhat curved, in correspondence with the concave profile of the centrum. Viewed in transverse sections (Fig. 19), the bony plates extend perpendicularly to

the surface and, hence, are radially arranged. The bony meshwork is somewhat denser at the periphery and near the upper and lower surfaces of the bodies than in the center, where, particularly toward the posterior surface, the cancellated tissue lodges large vascular channels. As the bodies have to bear the brunt of shocks and the strain of extreme flexion and extension, together with their great vascularity, they are predisposed to become the seat of tuberculous infection when the latter invades the spine. When once softened under inflammatory processes, their spongy texture leads to ready disintegration under the superimposed weight. The narrower parts of the vertebrae, as the pedicles, the laminae and the processes, also contain cancellated tissue enclosed within compact bone of varying thickness. Within the pedicles the plates are particularly strong, diverging into the surrounding bone and joining principally the horizontal lamellar system.

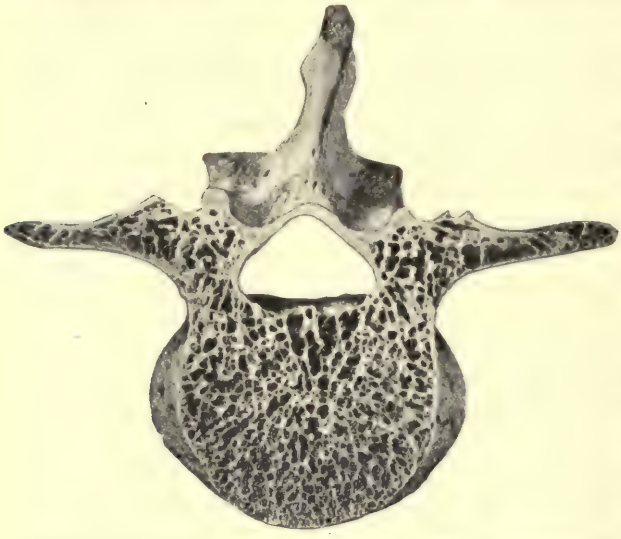

FIG. 19.—TRANSVERSE SECTION OF LUMBAR VERTEBRA.

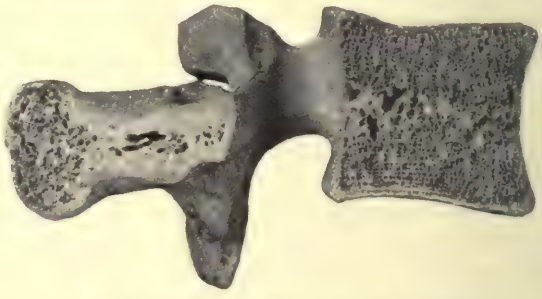

FIG. 20.—SAGITTAL SECTION OF LUMBAR VERTEBRA.

VESSELS AND NERVES OF THE SPINE

Arteries.—The arteries supplying the spine consist of vessels, for the most part of small size, derived from many sources. Thus in the cervical region the arteries are branches of the vertebral, the ascending cervical, the deep cervical and the occipital. Those nourishing the spine in the thoracic, lumbar and sacral regions are branches of the intercostal, lumbar and lateral sacral arteries. Many twigs destined for the vertebral bodies and their ligaments approach the anterior surface of the

spine and, after supplying the ligaments, enter the bodies by foramina situated at some distance on either side of the midline. Others are given off from the anastomotic arches formed by the spinal branches across the posterior surface of the bodies, between the latter and the posterior longitudinal ligament, and enter the bodies behind. The communications between the spinal branches also supply twigs that enter the anterior surfaces of the vertebral arches and, likewise, those for the capsules and the articular processes. Additional twigs behind may come from the deep muscular branches of the intercostal and lumbar arteries.

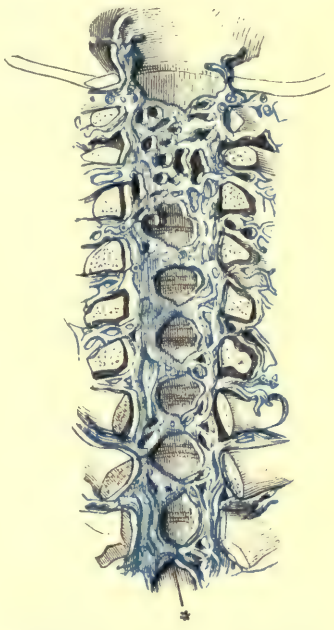

FIG. 21.—VENOUS PLEXUS ON ANTERIOR WALL OF VERTEBRAL CANAL, EXPOSED BY REMOVAL OF NEURAL ARCHES AND SPINAL CORD; CERVICAL REGION. (Breschet.)

O, Occipital bone in section.

Veins.—The veins, formed by radicles originating from the wide capillaries of the marrow tissue, accompany the arteries in a general way. Some of those from the cancellated tissue of the bodies make their exit in front and communicate with the *anterior external vertebral plexuses.* Other large venous channels terminate behind in the *venae basivertebrales,* which are tributary to transverse anastomosing stems that connect the anterior longitudinal vertebral plexuses. The transverse anastomoses present dilations opposite the depressions on the posterior aspect of the bodies, where they receive the venae basivertebrales. The *anterior longitudinal vertebral plexuses* are two venous networks that lie within the vertebral canal, at the sides of the posterior longitudinal ligament, within the peridural areolar tissue, and communicate with two less marked networks, the *posterior longitudinal vertebral plexuses,* running along the internal surfaces of the neural arches. In this manner the space between the dural sac and the wall of the vertebral canal is occupied by an irregular network or sinus of veins, which communicates laterally with the intervertebral veins and behind with the *posterior external vertebral plexuses.* The latter lie in the vertebral grooves, surrounding the spinous, articular and transverse processes, and communicate with the internal plexuses and drain into the vertebral, intercostal and lumbar veins. The posterior parts of the vertebrae are drained by small veins that open into the posterior longitudinal vertebral plexuses.

The *intervertebral veins* collectively carry off a large part of the blood gathered from the vertebrae and the spinal cord. They pass through the

intervertebral foramina and open externally, in the cervical region into the vertebral veins, in the thoracic region into the intercostal veins, in the lumbar region into the lumbar veins, and in the sacral region into the lateral sacral veins.

Nerves.—The nerves of the spine are few in number and small in size. They are twigs from the posterior primary divisions of the spinal nerves.

Development of the Vertebrae

The development of the spine—of the ligamentous structures as well as of the vertebrae—is closely related to the primary segmentation, which the embryo early exhibits in the formation of the mesoblastic somites. Early in the third week of fetal life, about the sixteenth day, a series of

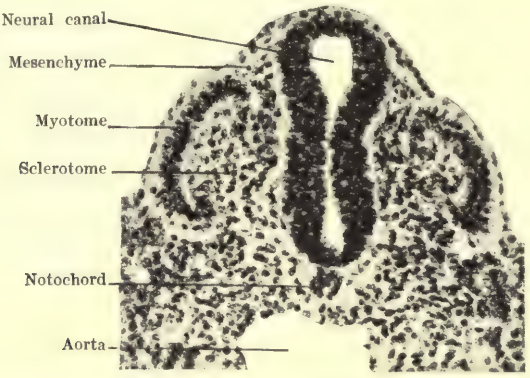

Fig. 22.—Dorsal Part of Transverse Section of Early Embryo. On either side of neural canal are seen the somites. × 140.

quadrilateral areas appears along the dorsal aspect of the embryo, on either side, lateral to the midline. The formation of the *somites,* as these mesoblastic areas are called, begins in the occipital region and progresses tailward. Subsequently, each somite differentiates into a denser, compressed C-form peripheral portion, the *myotome,* from which the segment of axial voluntary muscle arises, and a looser central part, the *sclerotome,* which extends mesially as the mesenchyme that surrounds the notochord and the neural tube. It is from this mesenchyme, derived from the somite, that the development of the spine proceeds.

In the higher vertebrates, the vertebrae pass through three phases in their development. At first, they are temporarily represented by consendations of mesenchyme; next, they are definitely laid down as masses of cartilage, which condition may be permanent, as in the sharks and other cartilaginous fishes; finally, among the higher types, the cartilage is re-

placed by bone and an osseous spine is attained. Three stages, therefore, are recognized: a membranous, a cartilaginous and a bony.

The *membranous stage* primarily involves the mesenchyme derived from the sclerotomes, which, being contributed by the somites, are ar-

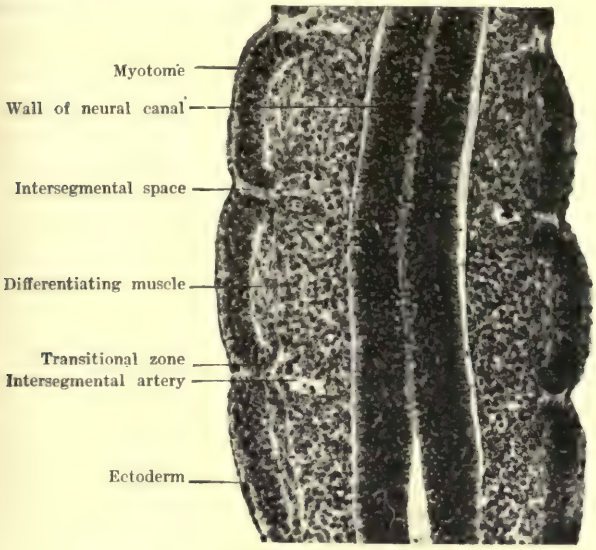

FIG. 23.—FRONTAL SECTION OF DORSAL PART OF EARLY EMBRYO. Somites lie on either side of the neural canal. × 100.

ranged segmentally and separated by the primitive intersegmental arteries. The sclerotome tissue immediately surrounding the notochord, however, loses all trace of segmentation and undergoes condensation to form the sheath of the notochord, while the more dorsal part of each sclerotome becomes divided by a narrow cleft into a cranial and a caudal part. A wedgelike medial outgrowth of the muscle-segment, the myotome, now forces itself between the two divisions of the sclerotome, which consequently tend to separate. The condensation of the caudal division proceeds in three directions: backward, to give rise to a dorsal or neural process; forward, to give rise to a ventral or costal process; and mesially, to form, with the corresponding process of the other side, a

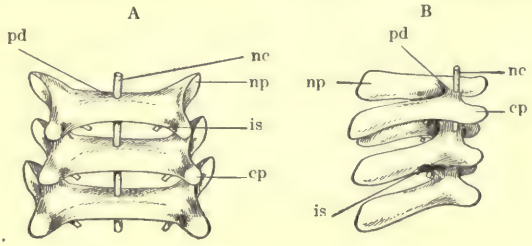

FIG. 24.—MODEL OF MEMBRANOUS STAGE OF DEVELOPING VERTEBRA; FROM EMBRYO OF 7 MM.

A, Ventral, B, lateral aspect; *nc*, notochord; *pd*, primitive disk; *np*, neural process; *cp*, costal process; *is*, intersegmental artery. × 15. (Bardeen.)

robust bar, the *primitive disk* of Bardeen, which encloses the notochord and fuses with the chordal sheath. The cranial divisions of the sclerotome, composed of much looser tissue, give rise to membranous expansions, which unite the dorsal processes of the scleromeres, *interdorsal membrane,* and fill in the space between the primitive disks, *interdiskal membrane,*

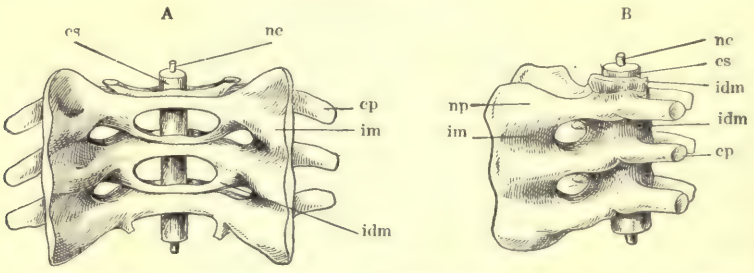

FIG. 25.—MODEL OF MEMBRANOUS STAGE OF DEVELOPING VERTEBRA; FROM EMBRYO OF 9 MM.

A, Dorsal, B, lateral aspect; *nc*, notochord; *cs*, chordal sheath; *np*, neural process; *cp*, costal process; *im*, interdorsal membrane; *idm*, interdiskal membrane. × 15. (Bardeen.)

surrounding the notochord and its sheath. The development of the bodies of the vertebrae proceeds within the loose tissue between the primitive disks. Since this tissue is contributed by the cranial division of one sclerotome and the caudal division of the preceding one, the formation of the permanent vertebrae brings about a secondary segmentation, which alternates with the primary one retained by the myomeres. The area of loose mesenchyme becomes separated into bilateral masses by a septum that grows out ventrally and dorsally from the notochordal sheath.

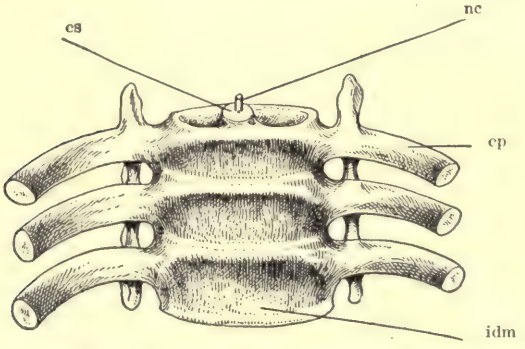

FIG. 26.—MODEL OF MEMBRANOUS STAGE OF DEVELOPING VERTEBRA; FROM EMBRYO OF 11 MM.; ANTERIOR ASPECT.

nc, Notochord; *cs*, chordal sheath and septum; *cp*, costal process; *idm*, interdiskal membrane. × 14. (Bardeen.)

The *cartilaginous stage* witnesses the appearance of three primary centers of chondrification about the same time: one for the neural process, one for the costal process and one for each half of the body of the permanent vertebra. At first, the cartilage of the two sides is separated by the perichordal septum, but soon this partition is disrupted and the cartilaginous anlages

unite and surround the notochord. An additional independent center appears for each rib. It will be noted that, both in the membranous and cartilaginous stage, the primitive body consists of two rudiments—a factor of importance in the production of the spina bifida anterior, in which cleavage of the vertebral body occurs. Subsequently, the differentiation of the permanent disks takes place by conversion of the embryonal hyaline cartilage into fibrocartilage. The thickened ventral part of the primitive disk, however, becomes cartilaginous only in the exceptional case of the first vertebra, this part ordinarily remaining fibrous and becoming incorporated in the permanent intervertebral disk as the annulus fibrosus. In the case of the first vertebra, however, the band, the *hypochordal bow* of some authors, undergoes chondrification and, finally, is replaced by bone to form the anterior arch of the atlas.

FIG. 27.—PRIMARY OSSIFICATION CENTERS.

Concerning the fate of the *notochord,* the primary axis of the body, it may be noted that, during the cartilaginous stage of the vertebrae, the notochord still extends the entire length of the column, as a rod, with sinuous outlines owing to alternate expansions and contractions, which in position correspond to the intervertebral disks and bodies of the vertebrae respectively. While within the bodies the notochord ultimately disappears, within the intervertebral disks it expands and is converted into a considerable mass, occupying the central part of the disk throughout life as the *nucleus pulposus.* The ligaments of the spine are derived from the surrounding mesenchyme, which undergoes the local condensation and histological change incident to the conversion of the embryonal connective tissue into the dense ligamentous structures.

The *bony stage* is ushered in by the appearance of the primary centers of ossification about the beginning of the third month of fetal life. There are three *primary centers:* one for the body and one for each half of the neural arch. Occasionally there is evidence that the body may ossify from a pair of centers. Although the ossific process gradually invades the cartilage, the three pieces of bone arising from the primary centers are still ununited at birth. The centers for the neural arch first appear in the locations of the later superior articular processes, from which they extend posteriorly into the laminae, laterally into the transverse processes, while ventrally they overlap the body to contribute the area which later, in the thoracic region, bears the facet supporting the ribs. The halves of the neural arch unite during the first year after birth. Ventrally, the bone of the neural arch remains ununited with that of the body for some considerable time, the intervening strip of cartilage, the neurocentral synchondrosis, not being effaced by osseous union until the fourth or sixth year. About the fifteenth year, or the age of puberty, the vertebrae reach

almost their full size and definitive form, although certain parts, as the ends of the spinous and transverse processes and the upper and lower surfaces of the bodies, are still cartilaginous.

There now appear five *secondary* or *epiphyseal centers* to complete ossification. The tips of the spinous and transverse processes ossify from

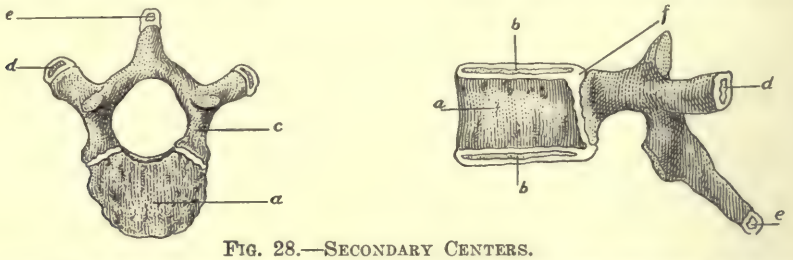

FIG. 28.—SECONDARY CENTERS.

a, Body; *b*, epiphyseal plates; *c*, neural arch; *d*, transverse process; *e*, spinous process; *f*, neurocentral synchondrosis.

centers that appear about the fifteenth and fuse about the eighteenth year. A thin epiphyseal disk is added to the upper and lower surfaces of the bodies by centers which appear from the sixteenth to the eighteenth year; although these plates join the body about the twenty-first year, the fusion is not complete until about the twenty-fourth year. In the sixth and seventh cervical segments, separate centers occur in the anterior root of the transverse processes and produce a costal element; when these persist, as they occasionally do, they give rise to *cervical ribs*. In the lumbar region, the so-called transverse process of the first lumbar vertebra may be provided with an independent center, which may either fuse with the transverse process, or remain separate and give rise to a *lumbar rib*. The mammillary processes are derived from independent centers developed on the superior articular processes of the last two thoracic and all of the lumbar vertebrae; these centers fuse about the twentieth year.

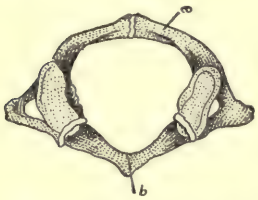

FIG. 29.—OSSIFICATION OF ATLAS.

a, For posterior arch and lateral mass; *b*, for anterior arch.

The Atlas.—The atlas is formed chiefly from two centers, one on each side, which give rise to the lateral masses, the posterior arch and the transverse processes. These centers, which correspond with those of the neural arch in other vertebrae, appear in the seventh week of fetal life, first in the roots of the posterior arch, from which points ossification proceeds rapidly backward. The halves of the posterior arch do not unite behind until the fourth year. The anterior arch is derived from the hypochordal bar, which only in the case of the atlas undergoes chondrification and, later, ossification. The body of the first vertebra unites with that of the second to become the odontoid process or dens of the axis.

The Axis.—The ossification of the second segment or epistropheus proceeds from five primary centers. About the seventh week of fetal life two centers, one on each side, appear laterally and give rise to the articular, transverse and spinous processes and the laminae. A median center, at first double, but soon fusing into a single one, forms in the lower part of the body about the fifth month. About the same time, two nuclei appear side by side in the upper part of the body, from which are derived a portion of the superior articular processes and the base of the odontoid process. The union of the odontoid process with the body and surrounding parts begins about the third year, but is not completed until a year or two later. The center of the junction is occupied by a small disk of cartilage that persists, surrounded by bone, until advanced age. Union of the three fundamental components of the axis, that is, the half-arches and the body, occurs about the fourth year, fusion of the hemi-arches behind and that of these with the body taking place about the same time.

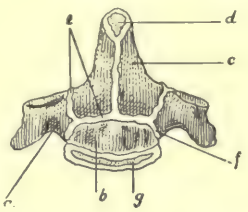

FIG. 30.—OSSIFICATION OF AXIS.

a, For articular, transverse and spinous processes and lamina; *b*, body; *c*, odontoid process; *d*, apex of odontoid; *e*, closes about third year; *f*, closes about fifth year; *g*, epiphyseal plate, unites about twenty-fifth year.

The Sacrum.—The sacral segments follow the usual plan of development, in so far that each arises from three primary centers: one for the body and one for each half-arch. The centers for the bodies of the first three sacral vertebrae precede ossification in the arches and appear during the third month of fetal life; those for the bodies of the last two segments are seen somewhat later, between the fifth and eighth month. The two centers for the half-arches, from which are derived the posterior portion of the alae, the articular processes and the laminae, are not present until the fifth or sixth month. Union of the arches with the bodies occurs between the second and sixth years, the junction being effected earliest between the lower segments and proceeding headward. Closure of the sacral canal, by fusion of the laminae, is delayed until the seventh to the fifteenth year, the laminae of the lowest segment usually failing to meet. Sometimes such incomplete union in-

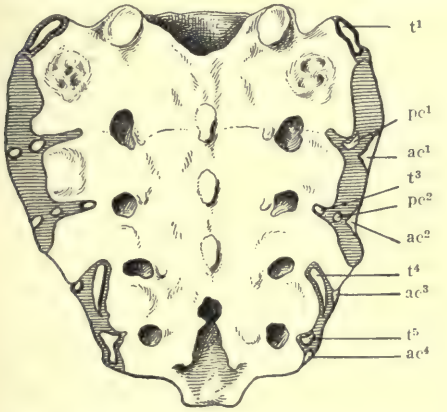

FIG. 31.—TRANSVERSE AND COSTAL EPIPHYSES OF SACRUM OF EIGHTEENTH YEAR.

t^1-t^5, Epiphyses of transverse processes; *ac* and *pc*, anterior and posterior costal epiphyses. (Fawcett.)

volves the higher vertebrae, with proportional increase in the bony gap.

The anterior parts of the lateral masses, regarded as representing costal elements, are formed from independent centers, which, for the upper three vertebrae, make their appearance from the fifth to the seventh fetal month, while costal centers of the fourth segment are not seen until about the third month after birth. Union between the costal centers and those for the neural arches occurs between the second and fifth years, the fusion giving rise, on each side, to that part of the lateral mass which supports the innominate bone. The costal elements unite with the bodies subsequent to their union with the neural arches.

The Coccyx.—The coccygeal segments are still cartilaginous at birth, ossification usually beginning some time later. Each vertebra ossifies from a single center. That for the first often appears during the first year, but may be delayed until the fourth; that for the second, from the fifth to the tenth; that for the third, about the fourteenth; and that for the fourth, about the fifteenth year. Separate ossific centers are formed for the cornua of the first vertebra.

The growth of the vertebral column results not only in changes in the form of the individual vertebrae, but also in the proportions of the presacral spine contributed by the different regions. In consequence, whereas in the child at birth the middle of the presacral spine falls within the seventh thoracic vertebra, in the adult the midpoint comes to lie within the ninth thoracic vertebra. According to Disse, the proportions of the three regions to the length of the presacral spine, this length being taken as 100, are: in the newborn child—cervical 26, thoracic 47 and lumbar 27; in the adult—cervical 22, thoracic 47 and lumbar 31. There is reason to believe, that the period between the twenty-first and twenty-fifth years, or just before consolidation is completed, is marked by growth more active than during the years immediately preceding.

Variations of the Vertebrae

Numerical Variations.—Deviations from the normal formula of the adult vertebral segments are relatively frequent, occurring in about 15 per cent of all spines. As might be expected from the developmental history of the coccyx, which is originally composed of four to six segments, increase in the total number of vertebrae is most often due to the retention of coccygeal segments that ordinarily are suppressed.

Variations of the presacral vertebrae fall into two groups: first, that in which increase or diminution occurs; second, that in which, while the total number of presacral vertebrae remains normal, the number of segments assigned to the different regions is altered. Numerical variations

of the sacral segments are also common, those of the lumbar less so, those of the thoracic still less frequent, while those of the cervical vertebrae are extremely rare.

Variations of the first group are probably dependent upon very early errors of segmentation of the axial tissue, as held by Dwight, Fischel and others. According to Bardeen, such variations are established by the sixth week of fetal life and probably persist to adolescence.

The second group of variations—in which the number of presacral vertebrae is normal, that is 24, but the number assigned to certain regions differs from normal—depends largely upon the influence exerted by the presence of supernumerary ribs or by the absence of suppressed ones.

An important factor in the addition of sacral segments to the movable

FIG. 32.—DEVELOPMENTAL DEFECTS OF NEURAL ARCHES.
A, Cervical vertebra (Disse); B, atlas.

vertebrae is the shifting tailward, which the ilium undergoes during its development. According to Bardeen, the definite attachment of the ilium to the vertebral column is established by the fifth week of fetal life, after which time no further change in its relation to individual vertebrae takes place.

It is evident that variations of the vertebral column do not arise from any single cause, but are the result of complex forces, and that the spine, as a whole, in attaining its definite relations, responds by coadaptation to the developmental processes affecting other parts of the skeleton, especially the lower extremities.

Anomalous Conditions.—The anomalous conditions of the adult individual vertebrae ordinarily represent arrest of normal development, and may depend, manifestly, upon either faulty processes of the membranous or cartilaginous stages, or imperfect ossification. Defects of the first class may give rise to profound malformations of the vertebrae, as absence of a half-arch, or half-body, while those of the second class account for imperfections of a lesser degree, as non-union of parts that usually undergo fusion.

Failure of the anterior arch of the atlas is due to faulty development of the hypochordal bow. At times, the ossification of the bow is incom-

plete, resulting in the production of an unattached anterior arch. In advanced life, frequently the borders of the vertebral bodies are greatly extended by irregular crenated fringes of bone. These prolongations, virtually exostoses, sometimes overlie the intervertebral disks and, in extreme cases, may curtail materially the movements of the spine.

The vertebral arches present defects with relative frequency. Usually, the abnormality consists in a more or less extensive deficiency in the posterior parts of the arches, which may be expressed by a mere cleft between ununited halves of spinous processes, or by a wide interval between the short and imperfect laminae. Imperfect union of the vertebral arches constitutes spina bifida, but in the condition to which the term ordinarily is applied, the imperfections of the vertebrae are associated with and secondary to more or less profound defects involving the spinal cord or its membranes. The spina bifida may be of any degree, from the involvement of only one or two vertebrae to the absence of all the arches. The defect occurs most frequently in the cervical region, next in the lumbar, and least often in the thoracic and sacral regions.

The Articulations of the Spine

The Intervertebral Disks

The presacral vertebrae are united by 23 intervertebral disks (*fibrocartilagines intervertebrales*), whose upper and lower surfaces coincide in form with those of the vertebral bodies between which they are placed. Their circumference, however, is somewhat greater than that of the bodies, so that the disks form a series of prominent zones, which alternate with the concave profiles of the bodies (Fig. 33). While the aggregate thickness of the disks is about one-fifth of that of all the presacral vertebrae, the proportion varies in the different regions. Thus, in the cervical region the proportion of the thickness of the disks to that of the vertebrae is about 1 : 5; in the thoracic region about 1 : 7; and in the lumbar region about 1 : 3.

With few exceptions, the intervertebral disks do not possess the same thickness at their anterior and posterior borders, but are usually wedge-shaped, this form being an important factor in producing the curves that distinguish the different parts of the column. The disks are the chief factor in maintaining the compensatory cervical curve, with its convexity directed forward. In the thoracic region, on the contrary, the disks are thinner in front than behind, here agreeing with the usual shape of the bodies in producing the concavity of the thoracic spine. But it is in the lumbar region that the wedge shape of the disks is most marked, as their anterior thickness greatly exceeds their posterior height.

Each disk is composed of two parts: a peripheral zone of tough fibrous texture, and a central portion, soft and spongy. The spongy center, the *nucleus pulposus,* represents the modified remains of the notochord, which, while disappearing entirely within the body of the vertebra, within the disk expands and persists as the soft pulpy nucleus. The position of the nucleus is generally eccentric, mostly behind the middle of the disk, although it may lie centrally, or rarely, even in the anterior part of the disk. As age advances, the density of the disk as a whole increases not only by

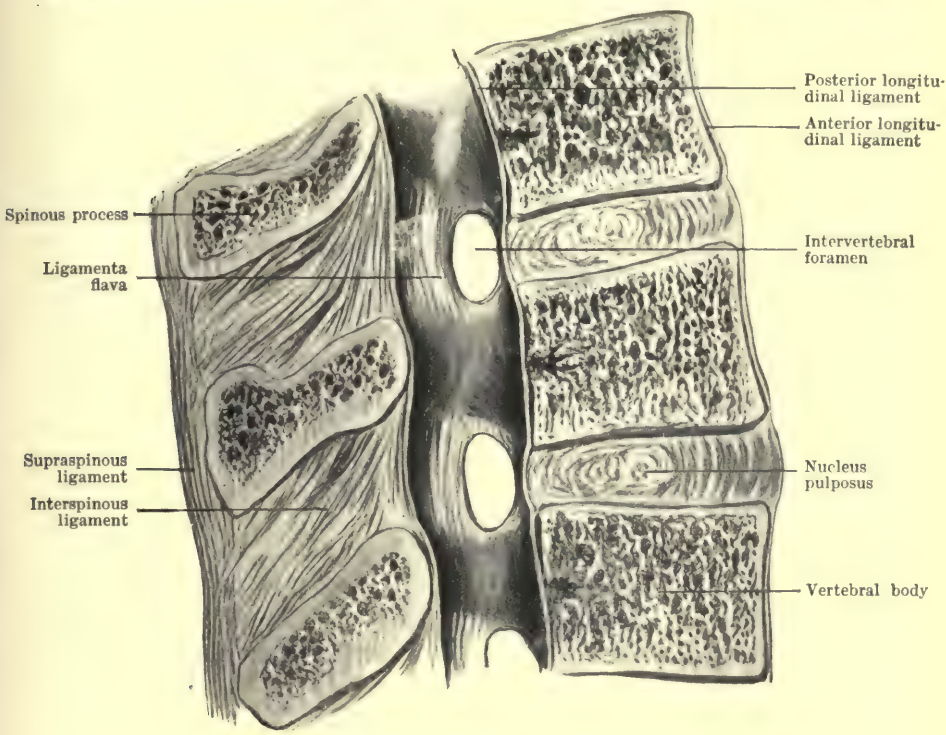

Fig. 33.—Sagittal Section of Lumbar Spine.

reason of the encroachment of the fibrous tissue upon the pulpy nucleus, but also because the latter itself becomes somewhat firmer.

With the exception of the superficial zone and the central spongy pulp, the entire disk is composed of fibrocartilage arranged as more or less concentrically disposed lamellae. The nucleus pulposus includes rounded nests of peculiar vesiculated cells, the descendants of the notochordal elements, which are imbedded in the soft ground substance.

The Ligaments

The Anterior Longitudinal Ligament.—This structure (*ligamentum longitudinale arterius*), also called the anterior common ligament, consists

of a broad band of longitudinal fibers, which extends from the anterior surface of the axis to the front of the first sacral vertebra. While conventionally described as beginning at the axis, in reality it is continued upward as a narrowed and thickened band to the occipital bone, in its ascent passing over the medial part of the atlanto-axial and the occipito-atlantal ligaments, with which membranous structures it blends. Although most intimately united to the intervertebral disks, the ligament is attached to the periosteum covering the anterior concave surfaces of the vertebrae (Fig. 33). This attachment, however, in places is incomplete to allow the passage of the nutrient blood vessels to the bone.

The Posterior Longitudinal Ligament.—This band (*ligamentum longitudinale posterius*) lies within the vertebral canal upon the posterior aspect of the vertebral body, and, therefore, can be seen to advantage only after removal of the posterior wall and contents of the canal. As the anterior one, so may the posterior ligament be followed from the coccyx to the skull. Broadening out to almost the full width of the intervertebral disks, to which the ligament is firmly attached, the intervening parts over the vertebral bodies are contracted to a narrow band—a feature conferring on the ligament markedly dentated lateral contours. While the broadest parts of the ligament are firmly attached to the fibrocartilage and the adjacent margins of the vertebral bodies, the narrowed portions bridge over the intervening surfaces of the bodies, thereby affording space for the unobstructed passage of the veins draining the vertebrae.

The Ligamenta Flava.—These ligaments constitute a series of elastic bands that fill the spaces between the laminae and thereby complete the posterolateral wall of the vertebral canal. They begin above with the interval between the arches between the second and third cervical vertebrae, and end below with the interlaminar space between the last lumbar and the first sacral segments. The ligaments consist of longitudinal bundles composed almost exclusively of yellow elastic tissue; hence the yellow tint indicated by their name. They are attached to the anterior surface of the lower border of the laminae of one vertebra and extend to the posterior surface of the upper border of the laminae of the next vertebra below.

The Interspinous Ligaments.—These ligaments (*ligamenta interspinalia*) are fibro-elastic membranous sheaths (Fig. 33) that fill the spaces between the spinous processes along the entire spine. In the cervical region, where they are continuous with the fibers of the nuchal ligament, their independence is masked; in the thoracic region, where the imbricated spinous processes lie close to one another, they are small and triangular; while in the lower thoracic and lumbar region, where the interspinous spaces are wide, the ligaments are large and quadrilateral.

The Supraspinous Ligaments.—The tips of the spinous processes are connected by a series of rounded bands (*ligamenta supraspinalia*), which, while blending in front with the interspinous ligament in the thoracic and

lumbar regions, maintain their independence. The ligaments (Fig. 33) consist of fibers of varying length—those of the deepest layer stretching between adjacent processes, those of the next layer bridging across two or three vertebrae, those most superficial connecting three or four segments.

The Intertransverse Ligaments.—These bands (*ligamenta intertransversaria*) stretch from the postero-inferior surface of one transverse process to the superior border of the one next below. They are to be regarded less as definite ligaments than as intermuscular septa.

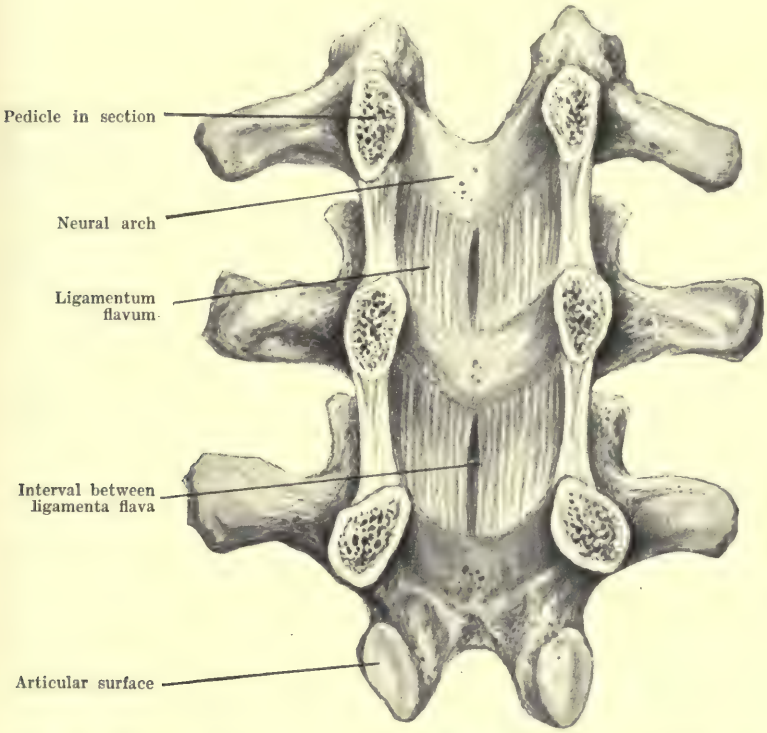

FIG. 34.—FRONTAL SECTION OF LUMBAR SPINE, EXPOSING LIGAMENTA FLAVA ON ANTERIOR SURFACE OF NEURAL ARCHES, AFTER CUTTING THROUGH PEDICLES.

Articulations between the Arches

Each typical presacral vertebra is provided with four articular processes, borne by the neural arch, by means of which it articulates with the contiguous vertebrae. These joints are true arthroidal diarthroses. The form and curvature of the articulating facets, as seen in the macerated bones, are somewhat modified by the articular cartilage that clothes the areas of contact. In general, the articular cartilages are thicker in

the center than at the periphery—a feature which tends to diminish the curvature presented by the bony surfaces.

Each articulation is enclosed by a capsular ligament (Fig. 38), which is attached to the articular process close to the joint and is lined with a synovial membrane as far as the surfaces of contact. The capsules are closest and tensest in the thoracic region; less so in the lumbar region; and most roomy and relaxed in the cervical region.

The Sacrococcygeal Articulation

The surface of union presented by the lower aspect of the fifth sacral vertebra is narrow and transversely oval and usually plane; the opposed surface of the coccyx is similarly shaped, but is often a little larger and slightly concave. The intervertebral disk uniting these surfaces is thin and ordinarily without a pulpy nucleus, although it often encloses a narrow rounded cleft. Frequently in men, less so in women, the first piece of the coccyx is joined by bony union in the sacrum. Occasionally in women, the ordinary union is replaced by a complete joint lined by a synovial membrane.

The *anterior and posterior sacrococcygeal ligaments,* which pass from the fifth sacral vertebra along the surfaces of the coccygeal segments, are virtually the continuations of the anterior and posterior longitudinal ligaments.

Although true articular processes between the sacrum and the coccyx are wanting, the cornua of these bones are covered with a thin layer of cartilage and connected by fibrous bands, the interarticular ligaments. These bands bridge over the exit of the fifth sacral nerve on each side and blend with the posterior sacrococcygeal ligament. At times they undergo ossification, in which case the cornua become united by bony fusion. The lower lateral angles of the sacrum are attached to the rudimentary transverse processes of the first piece of the coccyx by narrow fibrous bands, the *lateral sacrococcygeal ligaments.* Not infrequently these bands undergo ossification with the production of fifth sacral foramina with bony boundaries, through which pass the anterior divisions of the last sacral nerves. The lower opening of the sacral canal is covered by a membranous sheet of fibrous tissue, which extends from the edges of the cleft, that is the rudimentary neural arch of the fourth sacral vertebra, to the posterior surface of the coccyx. This sheet, the *median sacrococcygeal ligament,* closes in the extreme lower end of the vertebral canal—a space filled with loose succulent connective tissue.

The Intercoccygeal Articulations

The variability in the adult relations of the coccygeal vertebrae is reflected in the details of their bonds of union. Most commonly, the lower

two segments are joined by bony fusion, while the upper two are united by relatively loose connections. The latter usually include a fibrocartilaginous disk, in which suggestions of a peripheral fibrous ring and a pulpy center are recognizable, and anterior and posterior fibrous bands prolonged from the corresponding longitudinal ligaments.

Movements of the Spine

Were it not for the limitations imposed by the articulations between the arches of the individual vertebrae, the movements of the column formed by the bodies and the intervertebral disks would include a very wide range of motion in all directions. This is impressively demonstrated by preparations of the spine from which the neural arches with the articular processes have been removed, leaving only the bodies and disks. While the increments of motion between contiguous vertebrae are small, in the aggregate the movements are extensive and include flexion, extension, lateral flexion and torsion of the presacral spine. These movements are restrained by the longitudinal ligaments.

The elasticity and compressibility of the intervertebral disks are important factors tending to minimize the effect of shocks, while the oblique disposition of their fibers is well calculated to prevent separation and displacement of the vertebrae and to limit their torsion or rotation. The disks themselves determine to a considerable extent the freedom of motion enjoyed by any particular region, since where they are numerous, as well as proportionately thick, as in the neck, they favor mobility. In the thoracic region, on the other hand, where the disks are proportionately fewer and thinner than in the cervical part of the spine, movement is less extensive. In the lumbar region, the thickness of disks compensates for their small number and considerable motion is guaranteed.

In the fully articulated spine the movements are much more circumscribed, and, while as a whole they are considerable, the form and direction of the articular facets determine to a great degree the character and extent of the motion possible in the different regions. It is, however, to the articular processes that the spine owes its stability and capability of sustaining weight—for without these braces the column would be too yielding to give efficient support. Furthermore, the curves and planes of the articular facets are important factors in determining the character and extent of the movements between the vertebrae.

In the cervical region, where the articular surfaces are oblique and approximately plane, forward and backward flexion are extremely free (about 90 degrees), except between the second and third vertebrae, where ventral flexion is reduced by the thinness of the disk and the prolongation of the lip of the body of the axis. Lateral flexion is not favored by the

obliquity of the articular processes, but is possible to a considerable extent (30 degrees) by combination with torsion or rotation, when one of the upper processes glides downward and backward, while the other glides upward and forward on the corresponding surfaces of the subjacent vertebra. On the whole, however, dorsal and lateral flexion are freer in the neck than elsewhere in the spine; forward flexion is less extensive than in the lumbar region. It must be remembered that movements of the cervical spine are almost always associated with those of the head.

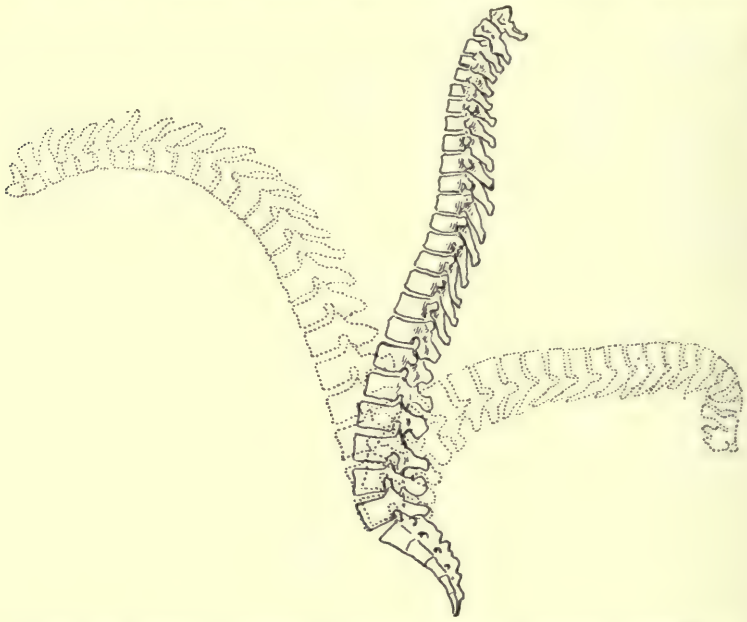

FIG. 35.—NORMAL CURVES OF ADULT SPINE IN UPRIGHT POSTURE.
Dotted outlines show curves in extreme flexion and extension; traced from actual preparations (Modified from Fick).

In the thoracic region the articular processes are practically vertical and do not agree in their disposition with the general curvature of the thoracic spine; therefore, they oppose ventral and dorsal flexion, which movements, moreover, are restricted by the attachments of the ribs, sternum and the imbrication of the spinous processes respectively. The articulating surfaces, however, are not bound together so tightly as to preclude a slight degree of anteroposterior motion. Lateral flexion, on the contrary, is free, although curtailed by the attachment of the thorax. A fair amount of rotation about a vertical axis is permitted, particularly in the upper part of the thoracic region, where a combination of lateral flexion and rotation or torsion may take place.

In the lumbar region, notwithstanding the unfavorable factors presented by the vertical position and anteroposterior concavity of the articu-

lar processes, a considerable amount of ventral, dorsal and lateral flexion occurs by reason of the looseness of the capsules of the articulation and the thickness of the intervertebral disks, which permit gliding of the joint surfaces upon each other. Thus, forward and backward flexion are very free, the former motion being usually regarded as reaching its maximum in the lumbar spine. Rotation, on the other hand, is precluded, although a combination of the various forms of flexion may give rise to circumduction. It will be noted that movements are freest in those parts of the spine having the convexity directed forward, where the intervertebral disks are thickest.

Union of the Spine and Skull

In contrast to the limited motion permitted between the individual vertebrae in other parts of the presacral spine, the attachment between the upper two cervical vertebrae, in conjunction with that between the atlas and the cranium, allows of a relatively great range of movement. Disregarding the combinations which are continually being made in effecting the movements between the head and spine, the motions are fundamentally of two kinds: nodding and rotary. The first of these is carried out between the skull and the atlas, and the second between the atlas and the axis.

The Occipito-Atlantal Articulation

This joint (*articulatio atlanto-occipitalis*), sometimes referred to as the upper articulation of the head, involves four articulating surfaces—two provided by the condyles of the occipital bone and two by the lateral masses of the atlas.

The *upper* or *condylar surfaces* are oval and so disposed that their long axes are directed obliquely, from in front outward and backward. The surfaces are convex from before backward and so twisted that, although nearly plane from side to side, they look slightly outward.

The *lower articular surfaces,* borne by the superior aspect of the lateral masses of the atlas, are in a general way reciprocally concave to receive the convex condyles, although measuring somewhat less in their long axes than the condyles.

The *capsular ligaments* surrounding the occipito-atlantal joints are quite relaxed and, on the skull, are attached some distance beyond the margin of the articular cartilages; on the atlas, this relation is more intimate.

Occipito-Atlantal Ligaments

In addition to the preceding articulations, surrounded by capsules, the skull and the atlas are connected by membranous expansions that enclose

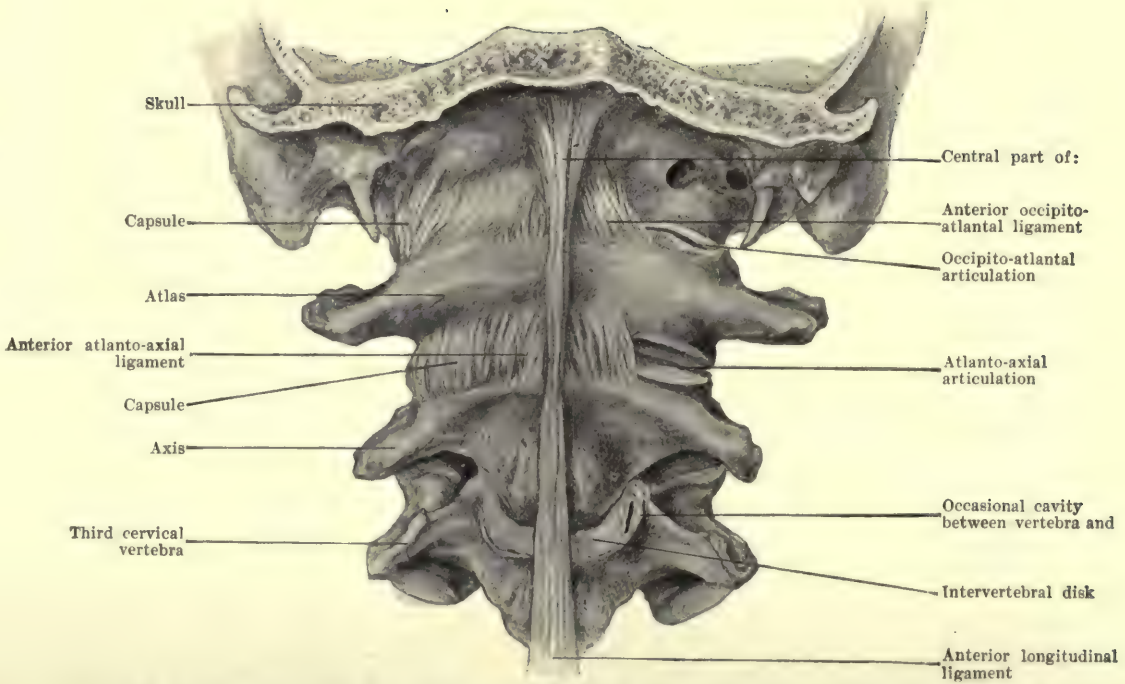

FIG. 36.—ARTICULATION BETWEEN SKULL AND UPPER END OF SPINE; ANTERIOR ASPECT.

the space, in front and behind, between the occipital bone and the arches of the atlas (Fig. 36).

The *anterior occipito-atlantal ligament* (*membrana atlanto-occipitalis anterior*) is a fibro-elastic sheet that stretches from in front of the foramen magnum to the upper surface of the anterior arch of the atlas; laterally it is attached to the arch as far as the occipito-atlantal joints, with the capsules of which it blends (Fig. 36). Medially, the membrane is strengthened by a narrow, but robust, band of vertical fibers, which represents the upper end of the anterior longitudinal ligament and is attached to the pharyngeal tubercle of the skull.

The *posterior occipito-atlantal ligament* (*membrana atlanto-occipitalis*

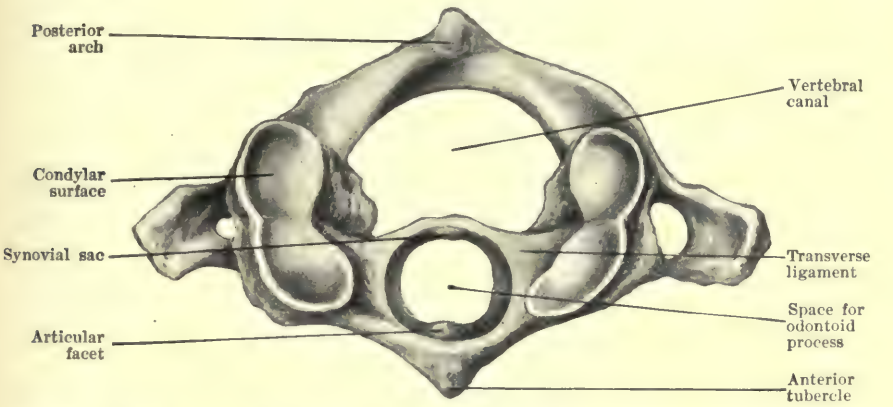

FIG. 37.—ATLAS WITH TRANSVERSE LIGAMENT, SHOWING SPACE OCCUPIED BY ODONTOID PROCESS, WHICH HAS BEEN REMOVED.

posterior) extends from the posterior margin of the foramen magnum to the upper surface of the posterior arch of the atlas. Since the space between the bones in question is greater behind than in front, the dimensions of the posterior membrane exceed those of the anterior sheet.

Articulations between Atlas and Axis

Since the particular purpose of the articulations between the first and second vertebrae is to facilitate transverse movements of the skull on the spine, the rotary diarthrosis between the odontoid process of the axis and the atlas is the chief anatomical factor concerned.

The odontoid process is provided with two *articular facets:* a vertically oval one in front, playing against the reciprocally articular surface on the posterior aspect of the anterior arch of the atlas, and an oval or round facet behind, in contact with the correspondingly shaped articular plate of fibrocartilage on the transverse ligament. Of the two delicate capsules surrounding these articulations, which are separate and unconnected, that

enclosing the anterior joint is more definite. The space enclosed by the atlas is subdivided by a dense band of fibrous tissue, the transverse ligament, into two compartments: an anterior one, much the smaller and occupied by the odontoid process, and a posterior one, the vertebral canal.

The Transverse Ligament.—The transverse ligament (*ligamentum transversum atlantis*) is a strong band that stretches between the rough-

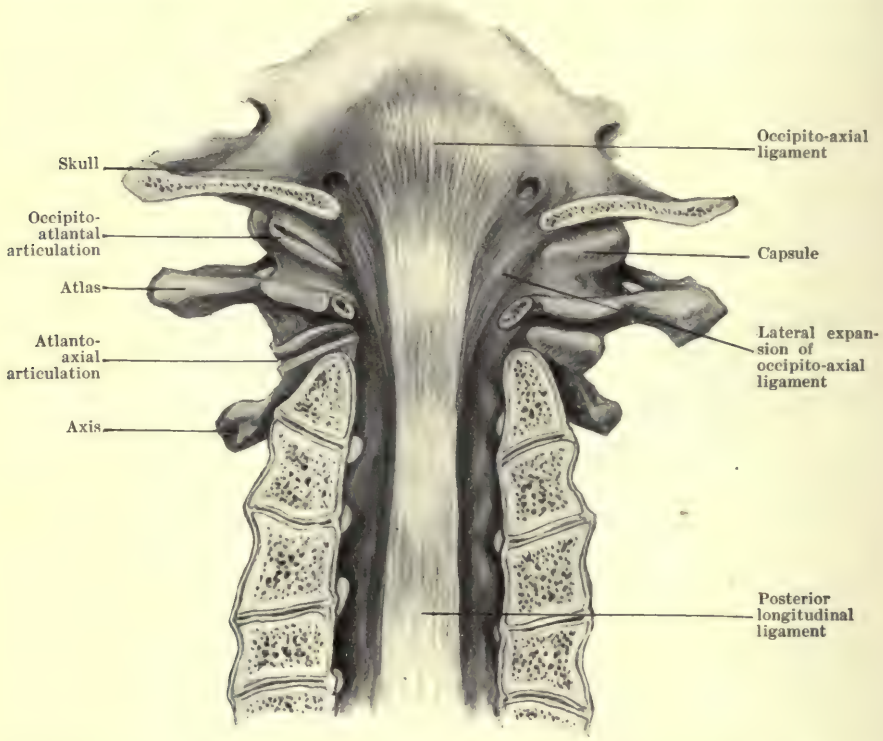

FIG. 38.—UNION BETWEEN SKULL AND SPINE.
Anterior wall of vertebral canal exposed by removal of neural arches and spinal cord; occipito-axial ligament undisturbed.

ened tubercles on the median surfaces of the lateral masses of the atlas and holds the odontoid process in place, preventing its dislocation backward. The band is broadest and thinnest in the middle, narrowest at the sides, and embraces closely the neck of the odontoid process. The flattened median portion of the band bears an oval plate of fibrocartilage for articulation with the posterior surface of the dens. The importance of the transverse ligament in preventing posterior displacement, and hence possible pressure on the spinal cord, is evident.

The posterior surface of the transverse band is extended upward and downward by tapering prolongations, which are attached to the anterior

margin of the foramen magnum and to the body of the axis respectively. These vertical expansions, in conjunction with the main transverse portion, confer on the entire structure, when viewed from behind, a shield or cross-like form, in recognition of which the term *ligamentum cruciatum* is often applied (Fig. 39).

In addition to the anterior articulation, between the odontoid process and the atlas, the joint surfaces on the inferior aspect of the lateral masses

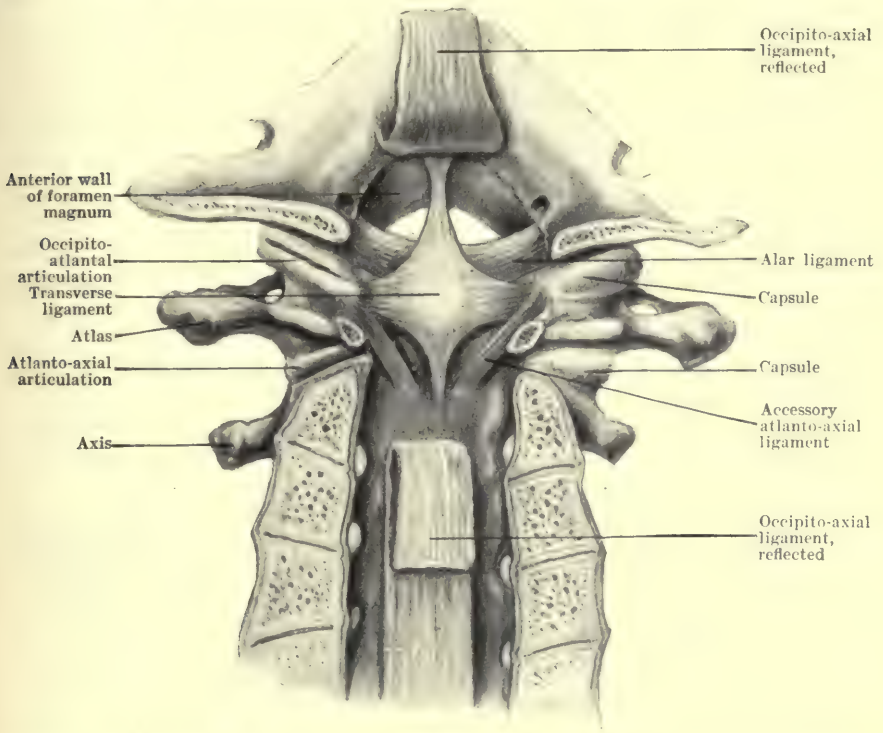

FIG. 39.—UNION BETWEEN SKULL AND SPINE.
Preparation similar to preceding, but occipito-axial ligament has been cut and reflected, exposing cruciate transverse and alar ligaments.

of the atlas play upon the contiguous articular facets of the axis. In contrast to the usual adaptation in the interneural series, the articular surfaces present marked incongruity, the facets being in only partial contact. The capsules are attached, so that almost the entire articular processes are free.

Alar Ligaments.—In addition to being held in place by the grasp of the transverse ligament, the odontoid process is attached to the occipital bone by strong fibrous bands that serve to limit the rotation of the skull on the spine. These bands, the *alar ligaments* (*ligamenta alaria*), often called the check ligaments, stretch obliquely upward and outward on

either side, from the posterolateral surface of the summit of the dens to the depression on the forepart of the medial border of the condyle of the occipital bone. They limit rotation of the skull to about 30 degrees on each side.

The *apical ligament* (*ligamentum apicis dentis*) consists of a narrow strand of fibro-elastic tissue, which passes from the apex of the odontoid process to the middle of the inner surface of the anterior margin of the foramen magnum. Functionally it is of little importance, but is of

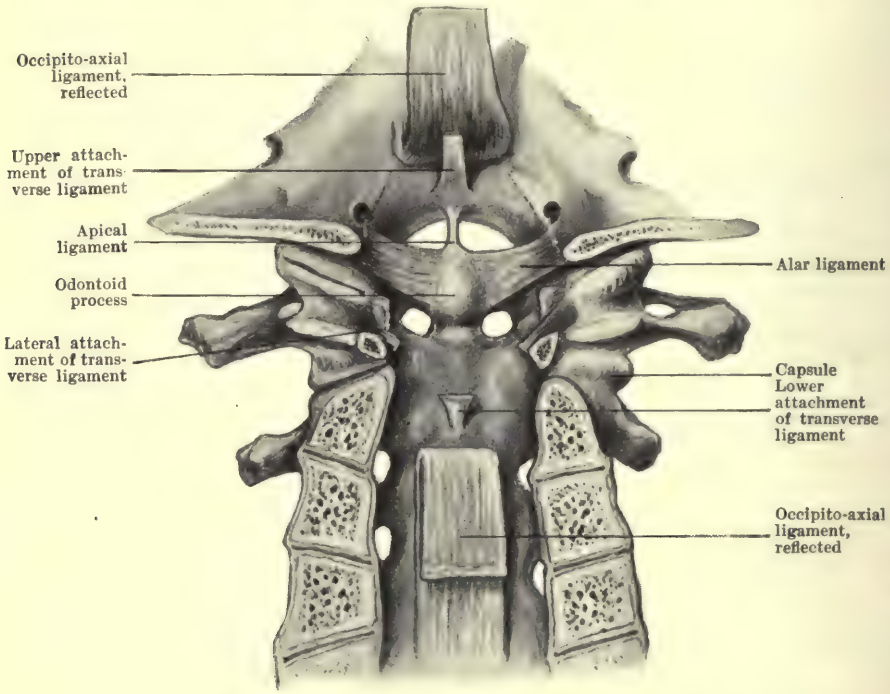

FIG. 40.—UNION BETWEEN SKULL AND SPINE.
Same preparation as Fig. 39, after removal of transverse ligament, exposing odontoid process with alar ligaments.

morphological interest as representing the remains of an intervertebral disk and the enclosed notochord.

The Occipito-Axial Ligament

After removing the vertebral arches, the spinal cord and the associated structures, a membranous sheet of fibrous tissue is seen stretching from the axis to the upper surface of the basi-occipital bone, being virtually the prolongation of the posterior longitudinal ligament (Fig. 38). This sheet, the *occipito-axial ligament* or *membrana tectoria,* entirely

covers in the odontoid process and its ligaments and completes the anterior wall of the vertebral canal in this part of the spine. The membrane is continuous with the posterior longitudinal ligament. It widens in its ascent and is attached to the basilar groove, above the anterior margin of the foramen magnum.

Atlanto-Axial Ligaments

These structures are continuations of the membranes connecting the skull and the atlas and, like them, enclose the space in front and behind, lying medial to the chief articulations.

The *anterior atlanto-axial ligament* (*membrana atlanto-axialis anterior*) extends from the inferior surface of the anterior arch of the atlas to the anterior border of the body of the axis, being thinner and looser than the membrane between the skull and atlas.

The *posterior atlanto-axial ligament* (*membrana atlanto-axialis posterior*) is attached above to the inferior surface of the posterior arch of the atlas and below to the upper margin of the laminae of the third cervical vertebra. In position, therefore, it corresponds to the ligamenta flava, but in structure the membrane is much more fibrous and less elastic.

Movements of the Head on the Spine

The movements enjoyed by the skull in relation to the spine are so free that they resemble collectively those conferred by a limited ball-and-socket joint. It must be remembered, however, that this latitude depends in no small degree upon the associated movements of the cervical vertebrae, since in almost every movement of the head the neck is involved to some extent. When analyzed, the movements taking place within the head articulations proper are fundamentally of two kinds: the nodding motion, occurring at the occipito-atlantal joint, and the rotatory or side-to-side motion, taking place between the atlas and the axis.

The *nodding movements* take place around the transverse axis and include a maximum range of about 20 degrees forward and 30 degrees backward from a middle position, although subject to considerable individual variation. While neither pure rotation nor lateral movement is permitted, a small amount of lateral inclination is effected by combination with slight rotation, the head being turned to the opposite side. It is in this position, in which the anterior part of one condyle and the posterior part of the other rest on the atlas, that the head gains greatest stability on the spine, and is the one instinctively assumed when the head is at rest.

The *rotary movements* of the head, such as used in expressing negation, take place between the atlas and the axis, the skull, locked with the atlas, revolving around a vertical axis passing through the odontoid

process. Although the chief movements are effected by rotation of the dens within the ring formed by the anterior arch of the atlas and the transverse ligament, the lateral atlanto-axial articulations give the stability insuring the necessary support to the head. When strictly limited to the atlanto-axial articulations, rotation probably does not exceed 30 degrees on either side, the wider excursions of the head being associated with more or less extensive torsion of the cervical vertebrae.

THE SPINAL CORD

The spinal cord (*medulla spinalis*), closely invested by its nutritive membrane, the pia mater, hangs suspended within the upper two-thirds of the vertebral canal, surrounded by the protecting tube of dura mater and the enclosed cerebrospinal fluid. Cross section of the vertebral canal and its contents (Fig. 42) emphasizes the important fact that the dural sac is not applied closely to the wall of the canal, but is so much smaller than the latter that the sac is separated on all sides from the wall of the canal by an interval filled with loose fatty areolar tissue and blood vessels. This arrangement is, manifestly, of great advantage in permitting free movements of the spine without undue compression of the dural sac or of the blood vessels within the canal.

The Vertebral Canal

The vertebral canal is admirably protected in front by the substantial column formed by the vertebral bodies and the intervertebral disks, laterally by the transverse processes, and behind by the robust spinous processes, springing from the strong laminae. Its smooth lining is contributed by the periosteum in conjunction with the posterior longitudinal ligament and the ligamenta flava. Closed below by fusion of the anterior and posterior walls, the only openings into the canal, with the exception of the foramen magnum, are the intervertebral foramina.

Although presenting many individual variations as to shape, as seen in cross sections, the vertebral canal possesses a fairly constant form in the different regions of the spine. Thus, approximately circular at the foramen magnum, the canal soon acquires a triangular form, which it retains as far as the sixth cervical vertebra, when its outline gradually becomes oval. Throughout the thoracic spine the contour is oval, sometimes round; on reaching the lumbar region the canal manifests a tendency to become more triangular in outline; while within the sacrum the canal suffers diminution in its anteroposterior diameter, with lateral expansion, which gives a pronounced crescentric form to this part of the vertebral canal.

The canal presents two enlargements, one in the lumbar, and the other in the upper thoracic and cervical spine. The lower widening begins at the first sacral vertebra and extends upward to the fourth or third lumbar, with a transverse diameter of 4-5 cm. and a sagittal one of 3 cm. Gradually narrowing from the upper two lumbar vertebrae, the canal contracts into a tube which maintains a fairly constant size (ap-

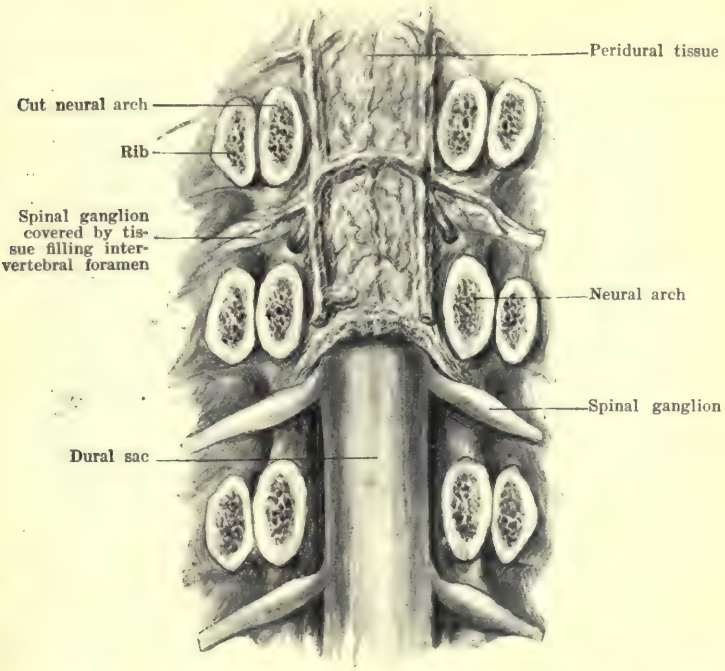

FIG. 41.—LOWER THORACIC CORD EXPOSED BY REMOVAL OF POSTERIOR WALL OF NEURAL CANAL.

In the upper part of figure, extradural tissue and vessels are undisturbed and cover cord and spinal ganglia; in the lower part, this tissue has been removed. Formalin preparation.

proximately 2 cm. by 1.5 cm.) to about the level of the seventh thoracic vertebra. Beyond this level, which, however, is one of much uncertainty, the canal gradually widens into the cervical enlargement, which attains its greatest dimensions (about 3 cm. by 2 cm.) between the sixth and fourth cervical vertebrae, becoming narrower above. It will be noted that the enlargements of the vertebral canal correspond in location with the parts of the spine which enjoy the greatest mobility, the cervical and lumbar regions.

The Membranes of the Spinal Cord

The membranes or *meninges* of the spinal cord are three; from without inward they are the dura mater, the arachnoid and the pia mater. They are directly continuous with the membranes surrounding the brain, being prolonged through the foramen magnum into the vertebral canal. The dura mater loosely invests the spinal cord and is the protecting envelope; the pia mater conducts the blood vessels to the spinal cord, to which it is closely applied, and is the nutritive membrane; while the

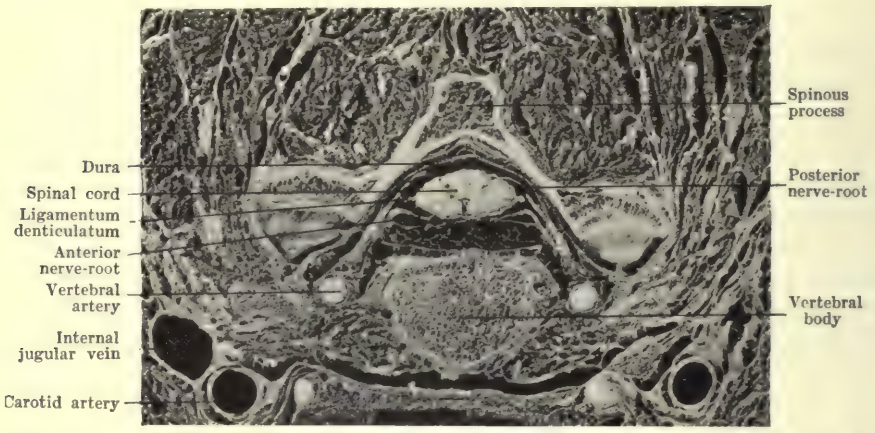

Fig. 42.—Cross Section at Level of Sixth Cervical Vertebra, Showing Spinal Cord and Membranes within Vertebral Canal.

intervening arachnoid contributes the delicate partition separating the cavity between the dura and the pia into the subdural and subarachnoid spaces.

The Dura Mater.—Within the cranium the dura mater consists of two layers, the outer of which assumes the rôle of periosteum of the skull, the inner layer forming the partitions separating the major divisions of the brain and containing the venous sinuses along the attached borders of these folds. At the foramen magnum these layers separate, the outer one blending with the periosteum and the ligaments lining the vertebral canal, and the inner one forming the robust dural sheath, that loosely invests the spinal cord as a tubular sac (Fig. 41). The dura mater spinalis extends from the foramen magnum, to the margins of which it is firmly attached, to the level of the second or third sacral vertebra.

Seen in cross section, the dural sac is oval in form, with a usual transverse diameter of 13-15 mm. and a sagittal one of 11-12 mm. It is, however, not of uniform size, but presents an enlargement in the lower cervical region, with a transverse diameter of 18-22 mm., and one in the lower lumbar region, below which the sac rapidly narrows within the

sacral canal. The thickness of the adult dura mater is about .4 mm. and is distinctly greater behind than in front. Its inner surface, the outer wall of the subdural space, is smooth and covered with a layer of endothelium. The outer dural surface, on the contrary, is roughened by the attachments of the strands of connective tissue occupying the peridural space (*cavum epidurale*). This interval between the dura mater and the vertebral canal, filled with fatty areolar tissue and thin-walled veins, usually measures 2-3 mm. in width, but in the lower lumbar region may be as much as 8 mm.

In addition to enclosing the spinal cord, the dura mater contributes

FIG. 43.—TRANSVERSE SECTION OF SPINAL CORD SURROUNDED BY ITS MEMBRANES. Dura and arachnoid are seen contributing sheaths to anterior nerve-root. × 6.

robust sheaths to the spinal nerves. On inspecting the inner surface of the opened dural sac, the exits of the nerves are located as pairs of small openings (Fig. 44) lying closely side by side and opposite the intervertebral foramina through which pass the anterior and posterior roots of the nerves. The roots do not actually pierce the dura, but, in a sense, push before them the membrane, which thus contributes a dural sheath. Each root of the nerve has its own sheath, which retains its independence as far as the spinal ganglion, where the two sheaths blend to become the external covering of the spinal nerve. As the two sheaths leave the dural sac, their opposed surfaces become united by connective tissue, so that both roots appear as if enclosed in a single sheath. The investment contributed by the dura mater contains an extension of the subdural space, which is

continued as a narrow cleft between the dural and arachnoid sheaths as far as the consolidated nerve. At this point the subdural space communicates with the perineural lymph channels within the covering of the nerve trunk.

The Arachnoid.—Although a very definite but thin membrane, the arachnoid is applied so closely to the inner surface of the dura mater, that the subdural space, separating the two membranes, is reduced to a narrow cleft not easily distinguishable with the unaided eye. Composed of fine bundles of fibro-elastic tissue and without blood vessels or nerves, the arachnoid sends trabeculae across the subarachnoid space to the pia mater, as well as contributing sheaths to the roots of the spinal nerves and the larger blood vessels crossing the space. The sheaths of arachnoid tissue surrounding the nerves accompany the roots for a short distance beyond the dural sac. In addition to covering the ligamenta denticulata, the arachnoid sends a median process toward the pia mater, which joins the latter along the posterior aspect of the spinal cord. This partition, the *septum posterius,* is incomplete in the upper part of the cervical region, being represented by strands connecting the two membranes; in the lower cervical and thoracic regions, however, the septum becomes a more definite partition.

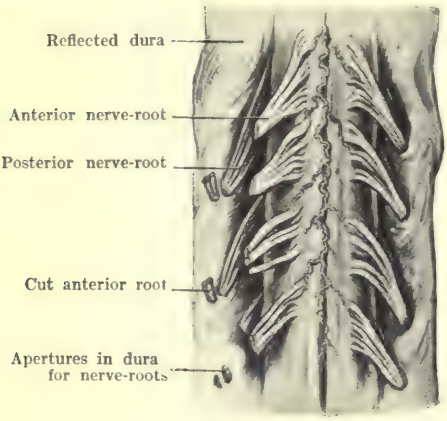

FIG. 44.—DURAL SAC CUT AND TURNED ASIDE, EXPOSING LOWER CERVICAL NERVE-ROOTS.
On right side of preparation, anterior roots are cut, showing passage of roots through dura.

The **subarachnoid space** (*cavum subarachnoideale*) lies between the arachnoid and the pia mater. In contrast to the narrow subdural cleft, it is of generous size and, being filled with the cerebrospinal fluid, provides an admirable receptacle for the spinal cord, within which the column of delicate nervous matter is suspended, surrounded and protected by a considerable layer of fluid. Directly continuous through the foramen magnum with the extensive subarachnoid cavity surrounding the medulla oblongata, on entering the vertebral canal the space narrows and becomes virtually co-extensive with the dural sac. Contracted in the middle of the thoracic region, where it possesses a diameter of 8-9 mm., the space widens greatly in the lumbar region, where it surrounds the voluminous mass of nerves forming the cauda equina. The free surface of the arachnoid and its prolongations is covered with a layer of endothelial plates.

The **cerebrospinal fluid** fills all parts of the subarachnoid space, as well as the insignificant subdural cavity. Although anatomical communication between the subarachnoid and subdural spaces does not exist, the meager quantity of fluid normally within the subdural space is chiefly derived from the cerebrospinal fluid, by osmotic passage through the delicate wall of the arachnoid. The cerebrospinal fluid surrounding the

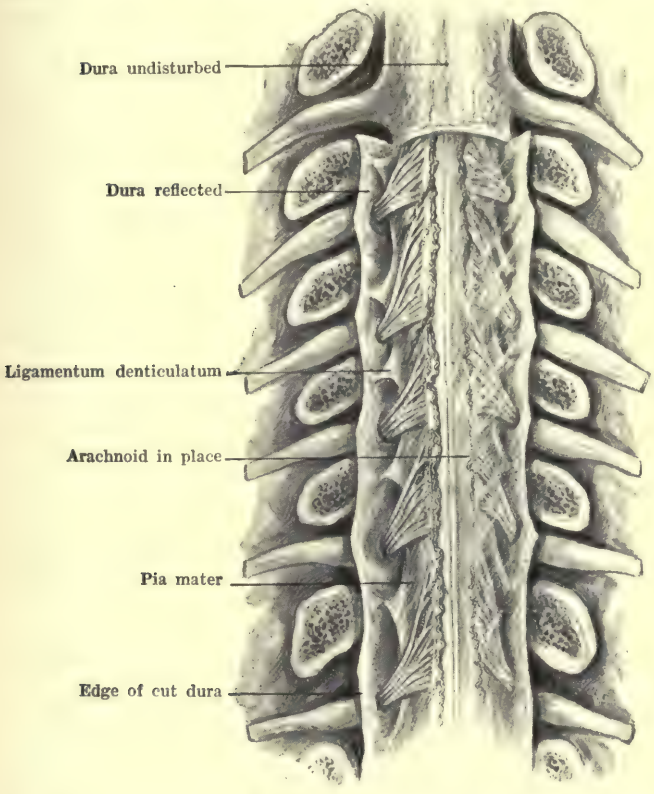

FIG. 45.—MEMBRANES OF SPINAL CORD.

Above, dura undisturbed; below, dura cut and reflected; on right side of preparation, arachnoid still in position; on left side, pia still covers cord; ligamentum denticulatum. Posterior view, lower cervical and upper thoracic nerves.

spinal cord is not produced *in loco,* but is derived from the fluid produced by the secretory activity of the choroid plexuses within the ventricles of the brain. Thence it escapes through the foramina of Megendie and of Luschka, in the roof of the fourth ventricle, into the large subarachnoid spaces ensheathing the brain-stem, from which it passes into the continuation of these spaces surrounding the spinal cord. In addition to the paths afforded by the sheaths accompanying the nerves, the Pacchionian granulations supply a means of escape for the cerebrospinal fluid into

the venous bloodstream within the sinuses of the dura mater encephali. The fluid within the subdural space, usually so small in amount as to do little more than moisten the walls of the cavity, escapes by means of the dural sheaths investing the spinal nerves.

The normal cerebrospinal fluid is a clear watery fluid, weakly alkaline or neutral in reaction, and of low specific gravity, about 1007. Ordinarily, it contains only from one to two per cent of solids, a small proportion of proteids, little or no albumin, and no fibrinogen. It reduces Feh-

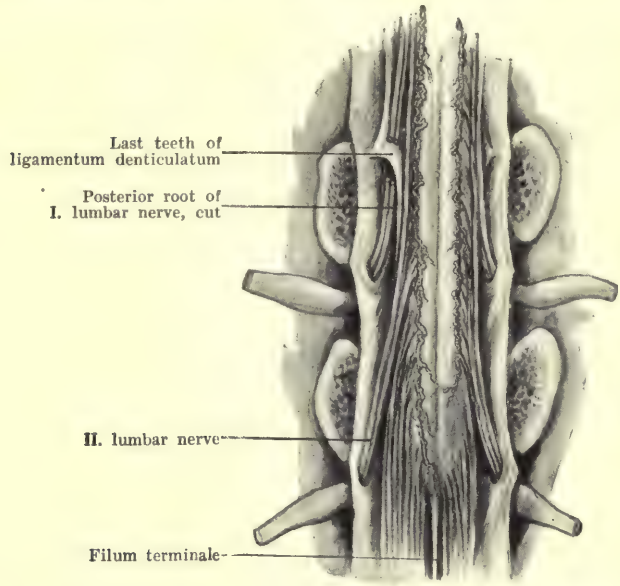

FIG. 46.—POSTERIOR ASPECT OF LOWER PART OF CORD, INVESTED WITH PIA AND SHOWING LAST TOOTH OF LIGAMENTUM DENTICULATUM.
On left side of preparation, posterior root of first lumbar nerve has been cut.

ling's solution, containing glucose in about the same concentration as blood serum. Except a few occasional leukocytes and endothelial cells, morphological elements are wanting.

The Pia Mater.—This envelope, the innermost of the three, is closely applied to the surface of the spinal cord. It also invests the roots of the spinal nerves with delicate sheaths, which accompany the roots across the subarachnoid space and fade away where the roots come into relation with the dural sheath. The pia mater spinalis is thicker than the pia mater cerebri and consists of two layers, an outer and an inner. The outer one is robust and composed of bundles of dense fibrous tissue; the inner one is thinner and includes delicate fibrous strands. On entering the cord, the blood vessels carry with them prolongations of the pial tissue, which thus contribute septa of connective tissue that penetrate the nervous

cylinder. In front of the anterior fissure, the pia mater is thickened to form a longitudinal glistening band, the *linea splendens,* that extends the entire length of the cord and ends below by blending with the filum terminale. Behind, the pia mater fills the posterior median sulcus, where that groove exists, and is intimately attached to the surface of the spinal cord along the posterior median septum. Laterally, the pia mater is continued on either side into an expansion, the *ligamentum denticulatum,* which, while its origin from the pia is continuous, is attached to the inner surface of the dura mater by the apices of a series of triangular processes (Fig. 45). This expansion springs from the lateral surface of the pial sheath and extends outward between the anterior and posterior roots of the spinal nerves, the attached points of the denticular processes being somewhat thickened. The denticulations, from twenty to twenty-two in number, are best developed and closest in the cervical region, the first one being attached immediately above the opening in the dural sac transmitting the vertebral artery, and the last one between the twelfth thoracic and the first lumbar nerve. Elsberg has called attention to the relations of the first lumbar nerve to the last process of the dentate ligament. This process is forked (Fig. 46), the shorter lateral prong being attached to the dura and the longer mesial prong passing to the side of the conus medullaris.

Form and Surface of the Spinal Cord

Denuded of its coverings and freed from the attached nerves, the spinal cord presents the general form of an elongated cylinder, compressed from before backward, that above is directly prolonged into the medulla oblongata and below terminates in a tapering end. The transition of the spinal cord into the medulla oblongata is gradual. For practical purposes the lower margin of the foramen magnum defines with sufficient accuracy the upper limit of the spinal cord. The position at which the adult spinal cord ends below is less certain, being subject to considerable individual variation. Usually the pointed tip of the cord lies opposite the lower border of the first lumbar vertebra, or the intervertebral disk between the first and second lumbar segments. In over 40 per cent, however, the cord ends at higher or lower levels, the range of ordinary variation being from the upper third of the first to the lower third of the second lumbar vertebra; as exceptional extremes, the twelfth thoracic and the third lumbar vertebrae have been recorded. In women the lower end of the cord more frequently (43.3 per cent) reaches the level of the second lumbar vertebra than in men (27 per cent). At birth, the lower end of the spinal cord lies opposite the third lumbar vertebra, the subsequent gradual ascent to its permanent adult level being brought about by the final adjustment of the cord and the spine.

Dimensions and Form.—The average *length* of the adult spinal cord

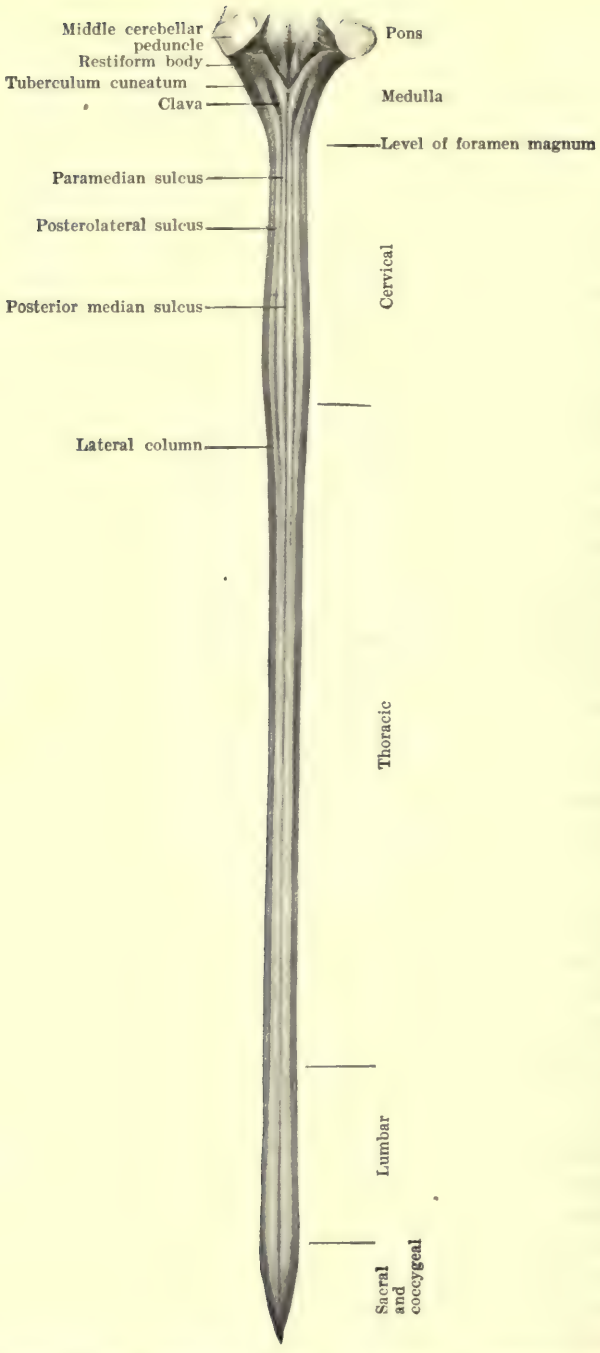

FIG. 47.—SPINAL CORD DENUDED OF ITS MEMBRANES; POSTERIOR ASPECT.

Above, cord is prolonged into medulla oblongata; below, it ends as rapidly tapering conus medullaris; cervical and lumbar enlargements. On right side, regions of cord indicated.

is 45 cm. (17¾ in.) in the male and 42 cm. (16½ in.) in the female (McCotter), or approximately two-thirds the length of the spine. Individual variations include cord-lengths of 44-50 cm. in the male and of 40-47 cm. in the female. Based on the levels at which the thirty-one pairs of spinal nerves are attached to its surface, the spinal cord is divided into cervical, thoracic, lumbar, and sacral regions, the cervical including approximately the upper fourth of the cord, the thoracic the following two-fourths, and the lumbar and sacral the remaining fourth.

The *diameters* of the spinal cord are not uniform throughout its length, but vary at different levels, so that when viewed from in front or behind, the profile of the cord is not that of a simple cylinder, but irregular. While the transverse or frontal diameter everywhere exceeds the sagittal, in the thoracic region the two diameters are 10 mm. and 8 mm. respectively. Here the cord is the smallest and most closely approximates a circular outline in cross section. Above and below, the cord exhibits thickenings, known as the cervical and lumbar enlargements. The upper swelling, *intumescentia cervicalis,* begins a short distance below the pyramidal decussation and ends at about the level of the second thoracic vertebra, gaining its maximum expansion opposite the fifth or sixth cervical vertebra, with a frontal diameter of 13-14 mm. and a sagittal one of 9 mm. The lower enlargement, *intumescentia lumbalis,* begins gradually at the level of the tenth thoracic vertebra, reaches its greatest expansion opposite the twelfth thoracic vertebra, and then passes, without demarcation, into the rapidly tapering conus medullaris. Its greatest diameters are frontal 11-13 mm. and sagittal 8-5 mm. The *conus medullaris* is usually regarded as including the last 10 mm. of the cord. The enlargements correspond to the segments of the spinal cord related to the large nerves supplying the limbs. The swellings appear in the fetus coincidently with the formation of the extremities, are relatively small before birth, and acquire their full dimensions only after the limbs have attained their growth. The *weight* of the adult spinal cord, stripped of its membranes, is usually a little less than 30 grams, 27-28 grams according to Ziehen, or about 1-2000 of the entire weight of the body; its proportion to the weight of the brain is 1 : 43. When fresh, the spinal cord possesses a soft cheesy consistence and a specific gravity of about 1034.

The lower tapering end of the spinal cord, the *conus medullaris,* is continued into a thread-like structure, the *filum terminale* (Fig. 48), which is distinguishable as a fine glistening filament, lying surrounded by the vertically disposed nerve-roots of the cauda equina within the dura mater. The filum is essentially a prolongation of the pia mater, covered by a sheath of arachnoid, and, therefore, consists chiefly of fibrous tissue which surrounds the termination of the anterior spinal artery and the accompanying vein, the latter vessel being of considerable

size. Within its upper third, however, the pial sheath encloses a thin and variable layer of nervous substance, which surrounds the terminal part of the central canal of the spinal cord and usually contains a few small nerve cells. On reaching the pointed lower end of the dural sac, at the level of the second sacral vertebra, the filum receives a sheath from the dura and proceeds downward through the lower end of the sacral

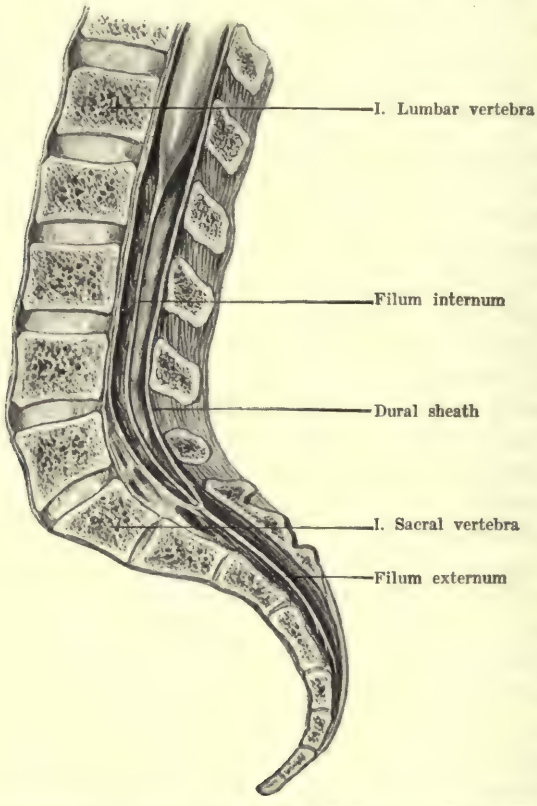

FIG. 48.—LOWER PART OF VERTEBRAL CANAL, SHOWING INTERNAL AND EXTERNAL PORTIONS OF FILUM TERMINALE. (Modified from Testut.)

canal to the dorsal surface of the coccyx, with whose periosteum it blends over the second coccygeal segment. The portion within the dural sac, the *filum terminale internum* (Fig. 48), measures about 16 cm. (6¼ in.) in length, while that outside the sac, the *filum terminale externum,* extends for about 8 cm. (3⅛ in.) farther.

Superficial Markings and Columns of the Spinal Cord.—Indications of a division of the spinal cord into symmetrical halves are seen on its ventral and dorsal surfaces. On the ventral or anterior surface is the *anterior median fissure* (*fissura mediana anterior*), a deep narrow cleft that extends the entire length of the cord and cuts into the cylinder 2-3.5

mm., or about one-third of its anteroposterior diameter. On the dorsal aspect of the cord, the division is much less evident, since only in the upper part of the cervical region, the lumbar enlargement, and the conus medullaris, a shallow groove, the *posterior median sulcus,* is present. On examining the spinal cord in transverse section (Fig. 49), however, a dense but narrow partition appears, which, as the *septum medianum posterius,* extends from the posterior surface to the middle of the cord and completes its separation into halves.

Each half is further subdivided by the lines, along which the root fibers of the spinal nerves are attached. The line of the dorsal or sensory

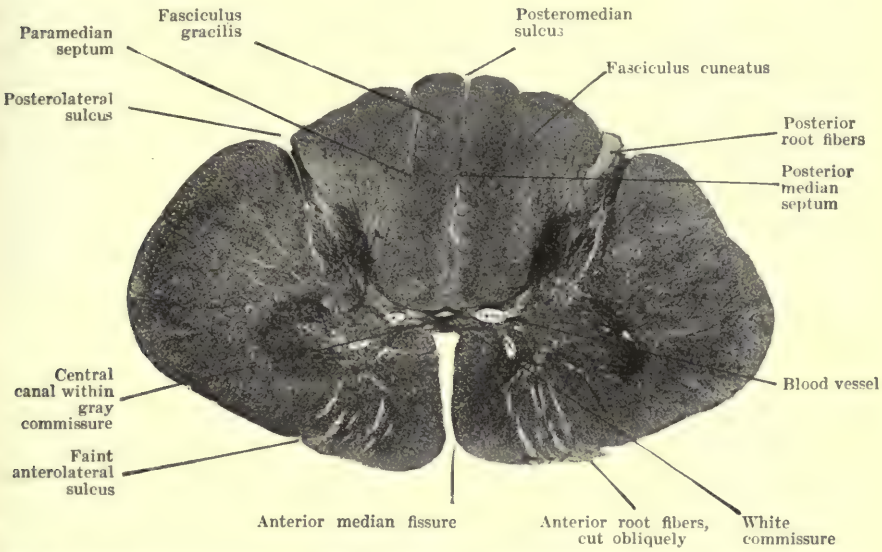

FIG. 49.—SECTION OF CERVICAL CORD, SHOWING DISTRIBUTION OF GRAY AND WHITE SUBSTANCE AND SUBDIVISION OF LATTER INTO COLUMNS BY SULCI AND NERVE-ROOTS. × 6.

roots, which is relatively straight and narrow, is marked by a distinct furrow, the *posterolateral groove* (*sulcus lateralis posterior*), that lies 2.5-3.5 mm. lateral to the posterior median septum and is continuous, being evident even in the intervals between the groups of fibers belonging to the adjacent nerves. The line of the anterior or motor roots is much less certain, since the fibers of the individual nerves do not emerge in one plane, but overlie one another to some extent, so that each group occupies a crescentic area. The anterior root-line lies 2-4 mm. lateral to the anterior median fissure and is neither marked by the distinct furrow nor continuous over the intervals between the groups of root bundles where the fibers are absent.

In this manner, in each lateral half of the spinal cord, a longitudinal tract, the *posterior column* (*funiculus posterior*), is marked off between

the posterior median septum and the groove of the posterior roots. This column includes something less than one-third of the semicircumference of the spinal cord, and measures about 6 mm. in the thoracic cord and 8 mm. and 7 mm. in the cervical and lumbar enlargements respectively. The tract included between the dorsal and ventral root-lines constitutes the *lateral column* (*funiculus lateralis*), while that between the most laterally emerging fibers of the ventral roots and the anterior median fissure forms the *anterior column* (*funiculus anterior*). Since such subdivision into anterior and lateral columns is uncertain and largely artificial, these are often regarded as forming a common *anterolateral column,* which embraces a little more than two-thirds of the semicircumference of the spinal cord. In the lower cervical and upper thoracic parts of the cord, the posterior column is grooved by a slight superficial furrow, the *paramedian sulcus* (*sulcus intermedius posterior*), that lies 1.5-2 mm. lateral to the posterior median septum. The paramedian sulcus corresponds in position to the peripheral attachment of a radial septum of neuroglia which penetrates the white substance of the cord for a variable distance and subdivides the posterior column into two unequal wedge-shaped tracts, of which the more median and smaller is the fasciculus gracilis or column of Goll and the lateral one is the fasciculus cuneatus or column of Burdach.

Internal Structure of the Spinal Cord

Inspection of the transversely sectioned spinal cord, even with the unaided eye, shows it to be composed of an irregularly outlined core of gray substance enclosed by a mantle of white matter (Fig. 43). Within each half of the cord, the gray substance forms a comet-shaped area, the broader end of which lies in front and the narrower end behind, with the concavity directed laterally. The convex surfaces of the areas of the two sides, which look toward each other and the midline, are connected by an isthmus of gray substance, the *gray commissure* (*commissura grisea*), that extends across the midline, somewhat in front of the middle of the anteroposterior diameter of the cord, and encloses the minute *central canal,* just visible to the unaided eye as a small speck. This canal subdivides the isthmus of gray substance into a dorsal and a ventral part, the *posterior commissure* and the *anterior gray commissure* (*commissura anterior grisea*), which lie behind and in front of the canal respectively. While the posterior median septum reaches the dorsal surfaces of the gray commissure, ventrally the latter is separated from the bottom of the anterior median fissure by an intervening bridge of white substance, the *anterior white commissure* (*commissura anterior alba*), which connects the anterior columns of the cord and provides an important pathway for fibers passing from one side to the other.

Proportions of Gray and White Substance.—In its entirety the gray matter, which in cross sections appears as an H-shaped area formed by the two crescents and the commissure, constitutes a continuous column, whose irregular contour depends not only upon the disposition of the gray matter, but also upon variations in its amount at different levels of the spinal cord. Thus, at the level of the first cervical nerve, the gray substance contributes a little more than one-fourth of the entire area of the cord; at that of the third nerve, something less than one-fourth; and at that of the seventh nerve, about one-third. In the thoracic part of the cord, where the gray substance reaches its minimum, between the level of the second to the eleventh nerve the gray column is practically uniform and is reduced to about one-sixth of the area of the cord. With the last thoracic nerve, the gray substance again increases to one-fourth and at the levels of the third and fifth lumbar nerves, to two-fifths and three-fifths respectively. In the sacral region, the relative amount of gray matter increases, at the level of the fifth sacral nerve reaching three-fourths. The absolute amount of gray substance is greatest within the cervical and lumbar enlargements, where it is directly related to the large nerves supplying the limbs. On comparing the white matter and the gray column (Fig. 50), it will be seen, that, while in the lower third of the lumbar cord these are of approximately equal area, below this level the gray substance exceeds the white. In the remaining regions, on the contrary, the white matter preponderates, in the larger part of the thoracic cord exceeding the gray substance from four- to five-fold and in the cervical cord being from two to three times greater.

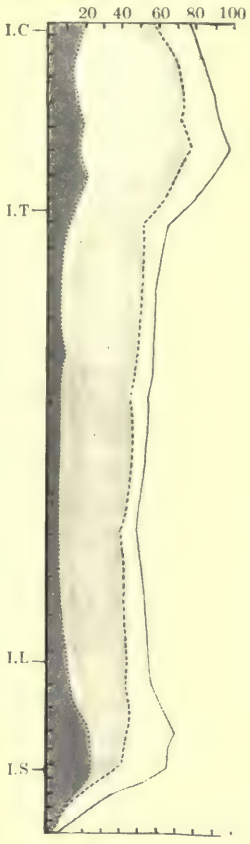

FIG. 50.—DIAGRAM SHOWING PROPORTION OF GRAY AND WHITE SUBSTANCE TO ENTIRE AREA OF SPINAL CORD.

Dark, light and white zones represent areas of gray and white substance and of the entire cord respectively. On left margin, cord-segments are indicated. (Donaldson and Davis.)

The Cord-Segments.—Although no suggestion of subdivision is to be seen as superficial constrictions, in principle the spinal cord may be regarded as consisting of a series of segments, each of which gives origin to the ventral (motor) and receives the dorsal (sensory) root fibers of one pair of spinal nerves. Corresponding with the attachment of these nerves, the spinal cord is conventionally divided

into cervical, thoracic, lumbar and sacral regions. Of the entire length of a cord measuring 43 cm., approximately 10 cm., or about 23.5 per cent, belonged to the cervical region; 24 cm., or 55.5 per cent, to the thoracic; 6 cm., or 14 per cent, to the lumbar; and 3 cm., or 7 per cent, to the sacral region.

The spinal nerves are attached to the surface of the cord by fan-shaped groups of the anterior and posterior root fibers that are gathered into compact bundles as they converge to form the common trunks. That portion of the spinal cord with which the root fibers of a spinal nerve are connected constitutes its cord-segment, the limits of which are defined by imaginary planes that pass through the intervals separating the extreme upper and lower fibers of the nerve from those of the adjacent nerves. In the thoracic region, these intervals are very evident, since the segments here are relatively long; in the cervical and lumbar regions, on the contrary, the segments are short and, in consequence, the root fibers are so crowded that they form almost unbroken rows. The length of the individual cord-segments varies; thus, according to the measurements of Lüderitz, those of the cervical region are 11-13.5 mm. in height; those of the thoracic region are 12-26 mm., the longest belonging to the fifth, sixth and seventh nerves; those of the lumbar region rapidly decrease from 15.5 to 5.5 mm., followed by a more gradual diminution to less than 4 mm. in the sacral region.

The Spinal Nerves

The nerves attached to the spinal cord are arranged as thirty-one pairs and, according to their relation to the vertebrae between which they escape from the vertebral canal, are grouped into eight cervical, twelve thoracic, five lumbar, five sacral and one coccygeal nerve. With the exception of the cervical series, in which the first nerve leaves the vertebral canal between the atlas and the skull, therefore above the first vertebra, and the eighth nerve between the seventh cervical and the first thoracic vertebrae, the spinal nerves are designated in agreement with the vertebrae below which they emerge, the third thoracic issuing below the third thoracic vertebra and the fifth lumbar below the fifth lumbar vertebra. The coccygeal nerve is occasionally absent, but, quite constantly, one or two additional pairs of rudimentary filaments are present below the thirty-first nerve. Ordinarily, these do not leave the dural sac, frequently remaining completely embedded in the pial sheath, and are to be regarded as rudimentary representatives of the caudal nerves of the lower animals. It may be of practical interest to note, in locating the last spinal nerve, that the coccygeal nerve, sometimes also the fifth sacral nerve, is often closely adherent, for quite a distance, to the filum terminale (Trolard).

Each spinal nerve is formed by the union of its anterior or ventral (efferent or motor) and posterior or dorsal (afferent or sensory) roots, of which the latter are not only usually the larger, but also are provided with fusiform swellings, the posterior root or *spinal ganglia* (Fig. 51). The nerve fibers composing the anterior roots emerge from the surface of the spinal cord over a crescentic field, the ventral root area. On issuing over these areas, the root fibers immediately form larger or smaller filaments, *fila radicularia,* five to ten in number, which converge and tend to collect into two main bundles before consolidating into anterior roots.

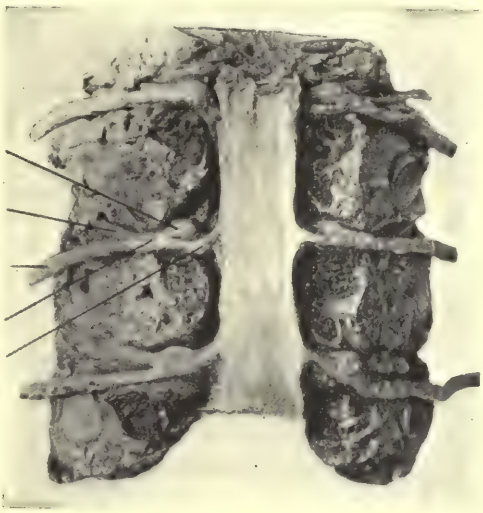
Spinal ganglion on posterior root
Posterior primary division of spinal nerve
Anterior primary division
Common trunk of nerve
Anterior root

FIG. 51.—DURAL SAC, NERVE-ROOTS, SPINAL GANGLIA, AND NERVES IN POSITION; ANTERIOR ASPECT.

The component fibers of the posterior roots, when they first enter the dural sac, are grouped into two large bundles; on approaching the cord, the filaments enter the nervous cylinder along the posterior root-line. Traced outward, the anterior and posterior roots, invested with sheaths of the pial and arachnoidal tissue, converge to the inner surface of the dura mater, which they traverse by separate but closely related openings (Fig. 44).

The anterior and posterior roots of the spinal nerves vary greatly in thickness, and, of course, in length, not only in the larger size of the posterior roots in comparison with the anterior, but often in the inequality of the roots of the two sides belonging to the same segment. The first cervical nerve, however, is an exception, in that its posterior root is smaller than the anterior. The following table, compiled from Stilling, gives the sectional areas in square millimeters of the individual roots, as well as the proportional areas of each root and of the combined roots;

in each case the area is reckoned in percentages, the largest area taken as 100.

INDIVIDUAL AND PROPORTIONAL AREAS OF ROOTS OF SPINAL NERVES

Nerve		Individual Areas (In square millimeters)		Proportional Areas (Largest root equals 100)		
		Ant. Root	Post. Root	Ant. Root	Post. Root	All Roots
Cervical	I	1.31	0.68	23	7	13
	II	2.78	4.06	48	42	45
	III	1.40	3.37	24	34	31
	IV	1.92	2.75	33	28	31
	V	5.51	4.73	96	49	67
	VI	5.64	8.92	98	92	96
	VII	4.58	7.58	79	79	80
	VIII	4.03	7.98	70	82	79
Thoracic	I	2.33	4.51	40	46	45
	II	1.07	2.05	18	21	20
	III	0.90	1.73	15	18	17
	IV	1.25	1.33	22	14	17
	V	1.29	1.48	22	15	18
	VI	1.05	1.26	18	13	15
	VII	1.07	1.25	18	13	15
	VIII	1.32	1.67	23	17	20
	IX	1.35	1.66	23	17	20
	X	1.17	1.53	20	16	18
	XI	1.07	1.79	18	19	19
	XII	1.11	1.90	19	20	20
Lumbar	I	1.19	2.58	21	27	25
	II	1.44	2.77	25	29	28
	III	2.97	4.86	52	50	52
	IV	5.77	6.52	100	68	81
	V	4.12	6.52	71	68	70
Sacral	I	4.73	7.61	82	79	81
	II	5.53	9.65	96	100	100
	III	2.50	4.77	43	49	48
	IV	0.80	2.36	14	24	20
	V	0.32	1.02	5	10	9
Coccygeal	I	0.05	0.18	1	22	2

From the foregoing figures it is evident that the largest roots are connected with the cervical and lumbar enlargements of the cord, the second sacral nerve leading in area, followed closely by the sixth or seventh cervical nerve. Stilling found the total area of the anterior roots to be 35-36 square millimeters, and of the posterior roots, 54-57 square millimeters. In a general way, according to Sappey, the diameters of the posterior roots bear to those of the anterior roots the proportion of 2:1 in the cervical region, 1:1 in the thoracic, 1.5:1 in the lumbar, and 1:1 in the sacral region.

Relations of the Nerves to the Spine.—The inequality in the rate of growth between the vertebral column and the enclosed spinal cord profoundly affects the relation between the levels at which the nerves are attached to the cord, and those of the intervertebral foramina through which they escape from the vertebral canal. Although these discrepancies between the levels of origin and of exit are insignificant in the upper part of the cervical series, below the third cervical nerve the differences constantly increase until, in the case of the last lumbar and of the last sacral nerve, the level of origin is separated from that of escape by

the distance of five and nine vertebrae respectively. Individual variations, which may amount to something more than the thickness of a vertebra, introduce a not inconsiderable element of uncertainty. In consequence of the increasing obliquity of their intradural course, the lower lumbar and sacral nerves descend almost vertically to make their escape, enshrouding the lower end of the cord with a mantle of nerve roots. When the dura is opened without disturbing the nerve roots, the latter are seen descending in two bundles, separated by a narrow triangular interval, in which the filum terminale appears (Fig. 52).

As shown by the determinations of Soulie, given in the following table, the intradural length of the spinal roots increases almost ninety-fold.

INTRADURAL LENGTH OF ROOTS OF SPINAL NERVES

(Average length in millimeters)

Cervical I	3	Thoracic I	29	Thoracic IX	52	Lumbar V	170
II	8	II	33	X	55	Sacral I	185
III	16	III	38	XI	58	II	196
IV	18	IV	43	XII	81	III	221
V	20	V	45	Lumbar I	91	IV	239
VI	23	VI	47	II	110	V	262
VII	25	VII	49	III	132	Coccygeal	266
VIII	27	VIII	49	IV	151		

From a practical standpoint, however, the relation of the levels of the cord segments is often of great interest. The most satisfactory data are those supplied by Reid, based on the examination of six adult male bodies. According to this investigator, these relations were found to be as follows, the highest and lowest levels observed being given.

II Cervical. Highest: Somewhat above posterior arch of atlas.
Lowest: Midway between posterior arch of atlas and spine of axis.

III Cervical. Highest: Somewhat below posterior arch of atlas.
Lowest: Junction of middle and lower third of spine of axis.

IV Cervical. Highest: Just below upper border of spine of axis.
Lowest: Middle of third cervical spine.

V Cervical. Highest: Just above lower border of spine of axis.
Lowest: Just below lower border of fourth cervical spine.

VI Cervical. Highest: Lower border of third cervical spine.
Lowest: Lower border of fifth cervical spine.

VII Cervical. Highest: Just below upper border of fourth cervical spine.
Lowest: Just above lower border of sixth cervical spine.

VIII Cervical.	Highest:	Upper border of fifth cervical spine.
	Lowest:	Upper border of seventh cervical spine.
I Thoracic.	Highest:	Midway between fifth and sixth cervical spines.
	Lowest:	Junction of middle and lower third of spine, between seventh cervical and first thoracic vertebrae.
II Thoracic.	Highest:	Lower border of sixth cervical spine.
	Lowest:	Just below border of first thoracic spine.
III Thoracic.	Highest:	Just above middle of seventh cervical spine.
	Lowest:	Lower border of second thoracic spine.
IV Thoracic.	Highest:	Just below upper border of first thoracic spine.
	Lowest:	Junction of upper and middle third of third thoracic spine.
V Thoracic.	Highest:	Upper border of second thoracic spine.
	Lowest:	Junction of upper and second fourth of fourth thoracic spine.
VI Thoracic.	Highest:	Lower border of second thoracic spine.
	Lowest:	Just below upper border of fifth thoracic spine.
VII Thoracic.	Highest:	Junction of upper and middle third of fourth thoracic spine.
	Lowest:	Just above lower border of fifth thoracic spine.
VIII Thoracic.	Highest:	Junction of middle and lower third of space between fourth and fifth thoracic vertebrae.
	Lowest:	Junction of upper and second fourth of sixth thoracic spine.
IX Thoracic.	Highest:	Midway between fifth and sixth thoracic spines.
	Lowest:	Upper border of seventh thoracic spine.
X Thoracic.	Highest:	Midway between sixth and seventh thoracic spines.
	Lowest:	Middle of eighth thoracic spine.
XI Thoracic.	Highest:	Junction of upper and second fourth of seventh thoracic spine.
	Lowest:	Just above ninth thoracic spine.
XII Thoracic.	Highest:	Junction of upper and second fourth of seventh thoracic spine.
	Lowest:	Just below ninth thoracic spine.
I Lumbar.	Highest:	Midway between eighth and ninth thoracic spines.
	Lowest:	Lower border of tenth thoracic spine.

II Lumbar.	Highest:	Middle of ninth thoracic spine.
	Lowest:	Junction of upper and middle third of eleventh thoracic spine.
III Lumbar.	Highest:	Middle of tenth thoracic spine.
	Lowest:	Just below eleventh thoracic spine.
IV Lumbar.	Highest:	Just below tenth thoracic spine.
	Lowest:	Junction of upper and second fourths of twelfth thoracic spine.
V Lumbar.	Highest:	Junction of upper and middle thirds of eleventh thoracic spine.
	Lowest:	Middle of twelfth thoracic spine.
I Sacral.	Highest:	Just above lower border of eleventh thoracic spine.
V Sacral.	Lowest:	Lower border of first lumbar spine.
Coccygeal.	Highest:	Lower border of first lumbar spine.
	Lowest:	Just below upper border of second lumbar spine.

It is evident from the foregoing data that individual variation is considerable, more so in men than in women, the origins of the thoracic roots, particularly of the fourth and sixth nerves, showing a difference of three spines. Notwithstanding these variations, it will be found usually true, that the origin of the second cervical nerve lies opposite the posterior arch of the atlas; of the first thoracic nerve, opposite the sixth or seventh cervical spine; of the seventh thoracic nerve, opposite the fourth or fifth thoracic spine; of the first lumbar nerve, opposite ninth or tenth thoracic spine; and of the sacral nerves, opposite the eleventh thoracic to the first lumbar spine, the origins of these nerves approximately corresponding in their position to the height of the body of the first lumbar vertebra. The anterior and posterior roots belonging to the same cord-segment are attached, according to Reid, to the same level, although the levels of the roots on the two sides sometimes differ.

Chipault gives the following summary of his determinations as to the relations between the levels of origin of the nerves and the spinous processes: In the cervical region, add *one* to the number of the spine to find the number of the root which springs from the cord at the same level; in the upper thoracic region, from the first to the fifth thoracic spine, add *two* to the number of the spine; in the lower thoracic region, from the sixth to the eleventh spine, add *three* to the number of the spine. The eleventh thoracic spine and the subjacent interspinous interval correspond to the origins of the last three lumbar nerves; the twelfth thoracic spine and the subjacent interspinous interval lie opposite the origins of the sacral nerves.

Owing to the relatively higher origin of the thoracic and first lumbar

nerves during early childhood, in order to make the above formulae applicable to children up to six or seven years of age, according to Chipault, slight modifications are necessary. In the upper thoracic region, from the first to the fourth spine, add *three* to the number of the spine; in the middle of the thoracic region, from the fifth to the ninth spine, add *four*.

The Spinal Ganglia

The trophic centers presiding over the afferent fibers composing the posterior roots of the spinal nerves are the nerve cells, which are gathered into ovoid enlargements, the spinal ganglia, lying along the dorsal roots of the nerves (Fig. 52). Each of the latter is provided on its posterior root, but not on its anterior, with such a ganglion, that in most cases lies within the intervertebral foramen, just centrally to the point at which the ventral and dorsal roots unite to form the short common trunk of the spinal nerve. In agreement with the size of the dorsal roots, the dimensions of the spinal ganglia vary, ordinarily their length being 5-7 mm. and their greatest thickness about half as much. They are usually fusiform or oval in shape, with the proximal pole bifurcated, to conform to the two chief bundles of the root fibers.

The first and second cervical nerves not being provided with intervertebral foramina, their ganglia occupy corresponding positions and lie on the neural arches of the atlas and the axis respectively. The spinal ganglia are situated just outside the vertebral canal, and, therefore, without the dural sac, except in the case of the coccygeal nerve, whose ganglia lie within the dura. Sometimes this exceptional location is shared by the small ganglion of the first cervical nerve; the ganglion may be rudimentary or absent, and, occasionally, the entire posterior root is wanting. Where the difference between the level of origin and of exit is considerable, as in the lower thoracic region, the obliquely descending intradural portion of the nerve makes a wide angle with the portion lying within the intervertebral foramen, whose course is approximately horizontal. The ganglia of the sacral nerves are located within the vertebral canal and, as in the case of the last nerve of the series, may be removed some distance from the place of exit.

Within the intervertebral foramina, the ganglia and trunks of the spinal nerves lie embedded in loose connective tissue (Fig. 41), uncertainly surrounded by the venous plexus formed by the tributaries that carry off the blood from the spinal cord and the vertebrae. The spinal rami of the intercostal, lumbar and other arteries also accompany the nerves through the foramina, the ganglia being provided with special twigs.

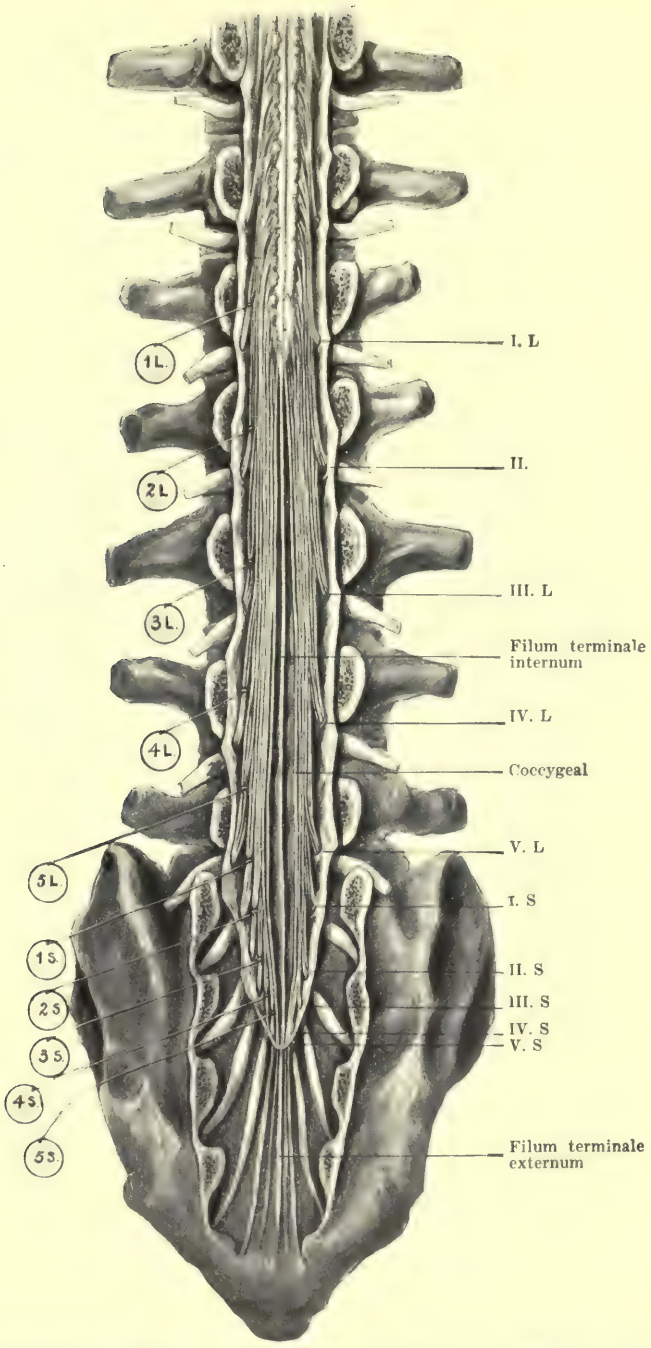

FIG. 52.—LOWER PART OF VERTEBRAL CANAL, AFTER REMOVAL OF NEURAL ARCHES.

Dural sac opened and partly removed, exposing end of cord with nerves descending to points of exit. On left, bundles of posterior root-fibers are shown; on right, exits of same nerves. Note interval between filum terminale and diverging nerves. Formalin preparation.

Blood Vessels of the Spinal Cord

Arteries.—The arterial supply of the spinal cord and its nerves is derived from the vertebral, the deep cervical and posterior rami of the intercostal, lumbar and lateral sacral arteries. Soon after entering the dural sac, each vertebral artery gives off from its medial side a small vessel, the posterior spinal artery, while farther along, just before uniting with its mate to form the basilar, an additional branch, the anterior spinal artery, also arises from the mesial aspect.

Spinal Arteries.—The two *anterior* spinal arteries extend caudally for a short distance, when they join at an acute angle to form an unpaired stem. The unpaired median stem descends along the ventral surface of the spinal cord as far as the fourth or fifth cervical nerve, at which point it joins the unpaired arterial chain formed by the anastomoses of the ascending and descending branches contributed by the spinal rami of the intercostal and lumbar arteries. The vessel thus formed is often called the *tractus arteriosus spinalis anterior* (Kadyi), but it may be regarded as a continuation of the anterior spinal artery which then is considered as maintaining its tortuous course the entire length of the spinal cord, ending below as a minute twig running along the filum terminale.

The *posterior* spinal arteries take origin from the vertebrals, directly after these vessels pierce the dura, and descend along the sides of the medulla oblongata and the spinal cord, usually in proximity to the root fibers of the spinal accessory nerves. At the level of the fourth or fifth cervical nerve, the artery of each side joins the longitudinal stem, *tractus arteriosus spinalis posterolateralis* (Kadyi), formed by the anastomoses of the branches contributed by the spinal rami of the intercostal, lumbar and lateral sacral arteries entering by way of the intervertebral foramina. Regarded as a continuous vessel, the posterior spinal artery may be traced as a small tortuous vessel to the lower part of the cord, where it terminates by joining the anterior spinal artery. The position of the posterior spinal artery is just in front of and close to the dorsal roots, sometimes, however, lying behind the nerves. Small branches are given off between the groups of posterior root fibers, which unite behind and medial to the posterior roots to form an additional longitudinal vessel, the *tractus arteriosus posterior.*

Interspinal Arteries.—These pass from various sources through the intervertebral foramina, along the entire length of the spine, and are derived from the vertebral and the deep cervical arteries in the neck, from the intercostal arteries in the thoracic region, and, lower, from the lumbar, iliolumbar and the lateral sacral arteries. Entering the intervertebral foramina, and, farther down, the anterior sacral foramina, each spinal branch divides; one part, the parietal, which is usually larger, goes to the bones and ligaments composing the walls of the vertebral canal.

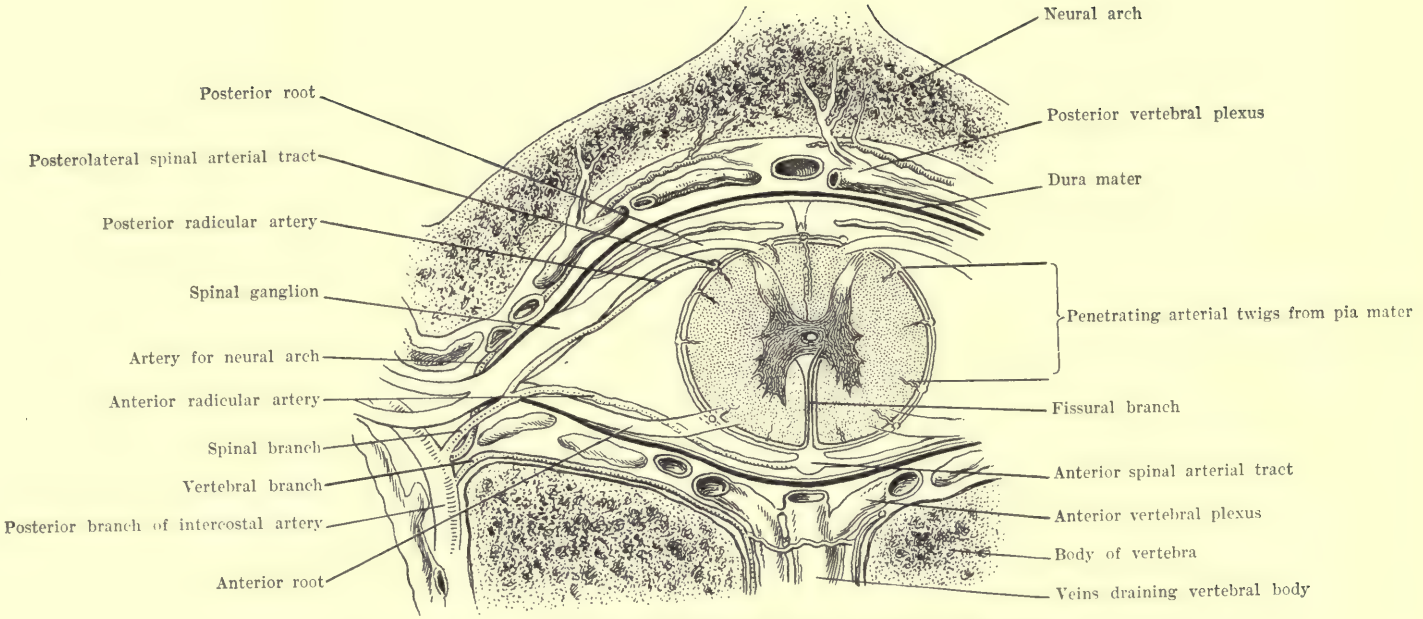

FIG. 53.—DIAGRAM OF BLOOD VESSELS OF SPINAL CORD AND VERTEBRAE.

The other part pierces the dural sheath enclosing the spinal nerves and provides small *radicular arteries* for the nutrition of the anterior and posterior roots of the nerves along which they, for the most part, end. While every intervertebral foramen is entered by an artery, the number of radicular branches, which pass along the nerve roots as far as the spinal cord, is decidedly less. Those reënforcing the median anterior spinal artery or tract vary in number and location, there being usually eight or nine such branches. Of these, the last one, or one of the lower twigs, is constantly of larger size, constituting the *arteria magna spinalis* of some authors. The branches reaching the spinal cord as prolongations of the posterior radicular arteries are more numerous, although of smaller size, than those accompanying the anterior roots, their usual number being sixteen or seventeen.

On reaching the spinal cord, both sets of vessels divide into ascending and descending branches, which by their union establish the longitudinal arterial tracts continuing the paths supplied by the anterior and posterior spinal arteries proper. In this manner, result three main channels, the unpaired anterior and the paired posterolateral arterial tracts. The latter give off horizontal branches, from which an additional longitudinal anastomotic chain, the tractus arteriosis posterior, arises on each side. All these tracts communicate so that the entire circumference of the spinal cord is enclosed by arterial circles.

Intraspinal Arteries.—The nervous substance of the spinal cord receives its immediate blood supply from the branches of the intraspinal arteries, which penetrate the nervous cylinder. The anterior median sulcus is occupied by more than 200 *fissural branches* given off from the anterior arterial tract. At the bottom of the sulcus these vessels bend to the right or left and, as the *central arteries,* pass through the anterior white commissure to the gray substance. The ramifications of the central arteries are distributed chiefly to the gray matter, but occasional twigs extend beyond to end within the adjacent white substance. Shortly after entering the gray core, the central artery gives off medially a relatively stout twig, that divides into an ascending and a descending branch for the supply of the deeper portions of the gray substance.

The numerous arterial branches passing into the periphery of the spinal cord are devoted largely to the supply of the white substance and include: (1) short twigs, distributed to the superficial parts of the cord; (2) longer twigs, the chief supply of the white matter, within which they form large meshed longitudinal plexuses; (3) penetrating twigs of considerable size, that traverse the intervening white matter to enter the gray substance. The capillary network within the gray substance is much closer than that supplying the white. The posterior median septum is accompanied into the cord by a series of unpaired twigs, the posterior median arteries, which supply the adjacent tracts of white matter. Addi-

tional sources of blood for the gray substance are contributed by the radicular arteries by twigs which accompany the anterior and posterior roots and are distributed to the respective cornua.

Veins.—The radicles of the central veins emerge along the anterior median fissure and unite to form a considerable trunk or plexus, the *anterior spinal vein* or *tractus venosus anterior,* which accompanies the corresponding artery the entire length of the spinal cord. Below, the anterior spinal vein begins on the filum terminale, ascends on the surface of the cord as a tortuous channel, and, above, continues over the medulla oblongata to resolve into the network of small veins enveloping the pons.

The dorsal aspect of the spinal cord presents another longitudinal unpaired and tortuous trunk, the *posterior spinal vein* or *tractus venosus posterior,* which usually consists of an irregular plexus, formed by the union of veins running lengthwise with irregular cross branches. The venules emerging from the lateral surface of the cord join with extensions from the anterior median tract to form an irregular anastomotic chain, *tractus venosus anterolateralis,* that lies on either side of the cord behind the anterior roots of the spinal nerves.

In addition to the paths at the upper end of the spinal cord, the most important channels providing escape of the blood from the anterior and posterior venous tracts, are the *radicular veins,* which accompany the nerve roots to the intervertebral foramina. After piercing the dura mater, both sets of radicular veins empty into the plexus formed by the veins returning the blood from the vertebrae; thence the blood passes, by way of the branches that traverse the intervertebral foramina, to the posterior rami of the intercostal, lumbar and lateral sacral veins.

Lymphatic Vessels.—These do not exist within the substance of the spinal cord. The chief paths for the escape of the lymph are the perivascular spaces within the adventitious coat of the blood vessels; at the surface of the cord, these perivacular channels communicate with the subarachnoid space.

Microscopical Structure of the Spinal Cord

Apart from the blood vessels and their accompanying tracts of connective tissue, the substance of the spinal cord is composed of nervous elements, the neurons, and the supporting tissue, the neuroglia. Both of these are derivatives of the invaginated ectodermic cells constituting the wall of the primary neural tube and, therefore, have a common genesis. According to the commonly accepted view, the neurons are the anatomical units of which the conducting paths within the cerebrospinal axis are made up by the chaining together of the links. Each link is a *neuron* consisting of: (1) the nucleated cell-body, usually spoken of as a nerve cell; (2) the branched dendritic processes; and (3) the axis-cylinder process

or axon, which usually is prolonged for a longer or shorter distance as the axis-cylinder of a nerve fiber. The *dendrites,* richly branched and ending in close relations with other neurons, conduct impulses towards the cell-body; while the *axon* conducts impulses away from the cell-body and gives off only one or two fine processes, the *collaterals.*

Each crescent of gray substance is divisible into three areas: the ventral and dorsal extremities that project beyond the level of the transverse gray commissure and constitute the anterior and posterior horns

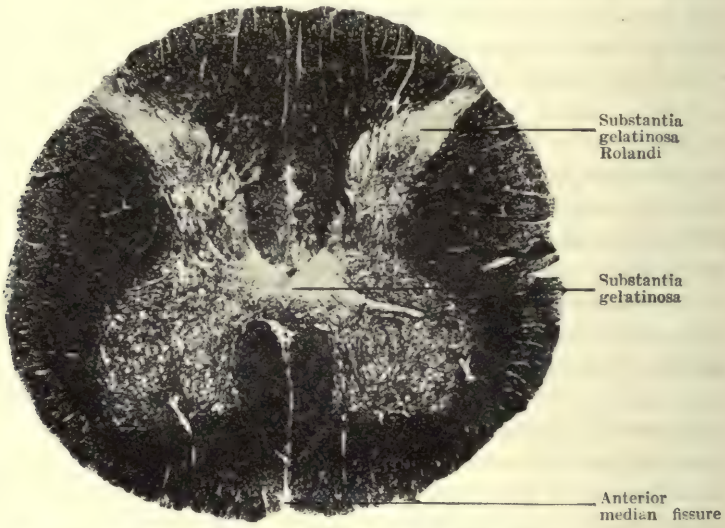

FIG. 54.—SECTION OF LUMBAR CORD; WEIGERT STAIN.
Substantia gelatinosa appears as light areas capping posterior horns and surrounding central canal. × 7.

or *cornua* (*columnae griseae*), and the intermediate portion (*pars intermedia*) that connects the cornua and receives the commissure.

The *anterior cornu* (*columna grisea anterior*) is short, thick and rounded, and separated from the adjacent surface of the cord by a considerable layer of white matter, through which the ventral root fibers proceed to their points of emergence. The blunt tip of the anterior horn constitutes the *caput cornu,* and the dorsal portion, by which it joins the commissure and the pars intermedia, the *basis cornu.*

The *posterior cornu* (*columna grisea posterior*) presents a marked contrast in being relatively long, narrow and pointed, and in extending peripherally almost to the posterolateral sulcus. The tip or *apex* of the dorsal horn is formed of a Λ-shaped stratum of modified gray matter, the *substantia gelatinosa Rolandi,* that appears lighter and somewhat less opaque than the subjacent broader portion of the horn, the *caput cornu,* which it covers as a cap. More ventrally, the posterior horn usually pre-

sents a contraction, known as the *cervix cornu* (*cervix columnae posterioris*).

The demarcation between the gray and white matter is broken along the lateral border of the crescent by delicate projections of gray substance into the adjacent lateral column. The subdivisions of these processes unite to form a network of gray matter, the interstices of which are occupied by longitudinally coursing nerve fibers, the whole giving rise to the *processus* or *formatio reticularis*. In the thoracic and upper parts of the cervical cord, the formatio reticularis is condensed into a compact process of gray substance, that is directed outward and constitutes the *lateral cornu* (*columna lateralis*).

The Gray Substance.—The most distinctive elements of the gray matter are the nerve cells, which lie embedded within a complex matrix, formed by the various processes of the neurons, the supporting neuroglia and the blood vessels. It is upon the rich supply of the capillaries, the absence of myelin and the pigment within the nerve cells, that the characteristic reddish-brown color of the gray matter largely depends.

The nerve cells of the spinal cord may be divided, according to the destination of their axis-cylinder processes, into the following groups:

1. Cells whose axons pass as efferent fibers to end outside the cerebrospinal axis. These are the anterior horn or radicular cells, that lie within the ventral cornua and give rise to the motor fibers emerging from the spinal cord as the anterior roots.

2. Cells whose axons pass into the white substance, where they divide into ascending and descending branches. The latter, after a short course, again enter the gray substance, where they end. The ascending branches course upward, within the divisions of the white matter and constitute the column cells. Of these two varieties are recognized: (a) *tract cells,* whose ascending branches or axons pass upward and constitute special paths connecting the spinal cord and the brain; and (b) *association cells,* whose ascending branches, that is, axons, after a longer or shorter course, again enter the gray substance at a higher level, and serve to unite different cord segments. The nerve-processes of association cells are known as endogenous fibers. The column cells may be further distinguished as *homolateral* and *contralateral,* the axons of the former passing into the white matter of the same side, those of the latter gaining the white matter of the opposite of the cord by way of the anterior white commissure. Such elements are called *commissural cells* and occur chiefly within the base of the dorsal cornua and the pars intermedia.

3. Cells of Golgi II type, found mostly within the posterior horns and the substantia gelatinosa Rolandi, whose axons never leave the gray matter, but resolve into the terminal arborizations after a short microscopic course.

Grouping of the Nerve Cells.—As seen in cross sections of the

spinal cord (Figs. 67 and 70), although widely scattered, the nerve cells are not uniformly distributed throughout the gray substance, but in certain localities, particularly within the anterior cornua, are collected into more or less definite groups or columns.

The *anterior horn cells* include two general collections, a mesial and a lateral group. These groups vary in different parts of the cord and, where well marked, are often made up of more than a single aggregation of cells. This is particularly true of the lateral collection, in which an anterior and a posterior subdivision are recognized as the ventrolateral

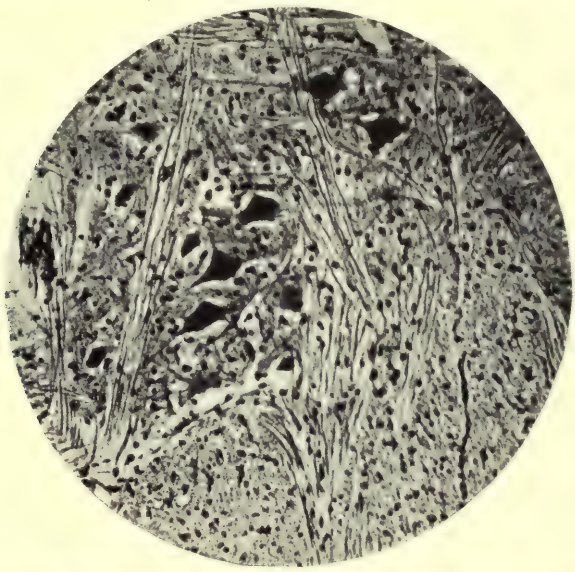

FIG. 55.—TRANSVERSE SECTION OF CORD, REGION OF ANTERIOR HORN, WITH NERVE CELLS AND CONVERGING AXONS OF VENTRAL ROOT. × 100.

and the dorsolateral group, that occupy the corresponding angles of the anterior cornu. The mesial collection of cells situated within the ventral angle is also, but much less distinctly, divided into a ventromesial and a dorsomesial group.

The *posterior horn cells* are neither as large nor as regularly disposed as the nerve cells of the ventral cornu. Only in one locality, along the median border of the base of the posterior horn, are they collected into a definite tract, the column of Clarke; elsewhere, they are scattered without order throughout the gray matter of the posterior cornu. The posterior horn cells, however, may be divided into: (1) the cells of Clarke's column, (2) cells of the substantia gelatinosa Rolandi and (3) the inner cells of the caput cornu.

The cells of *Clarke's column* (Fig. 56) form a conspicuous collection, that extends from the level of the seventh cervical to that of the second

lumbar nerve and is best developed in the lower thoracic region of the cord. In cross sections, the cell column appears as a group of multipolar cells, that occupies the mesial border of the base of the posterior horn and, where best developed, opposite the origin of the twelfth thoracic nerve, corresponds to an elevation on the surface of the gray matter. The nerve cells of the *substantia gelatinosa Rolandi* include innumerable small, for the most part stellate, elements. Their numerous short dendrites are irregularly branched and disposed; the axons are continued partly into the white matter of the posterior column and partly into the gray matter itself. The *inner cells* of the posterior horn, intermingled with numerous small elements within the head of the dorsal cornu, are triangular or fusiform and larger than the ordinary cells of the substantia gelatinosa.

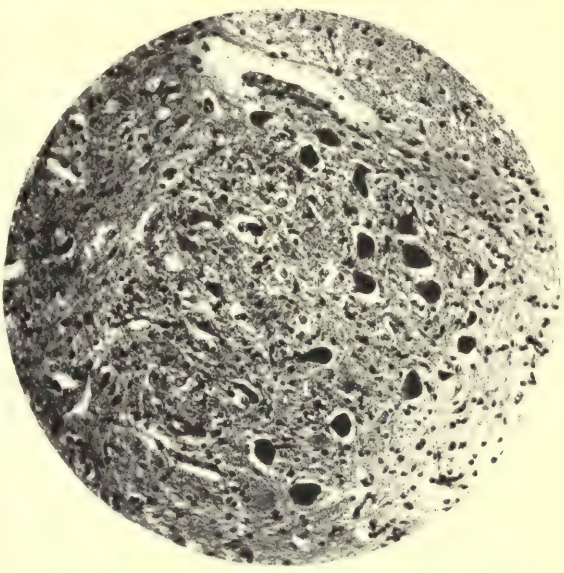

Fig. 56.—Nerve Cells of Clarke's Column. × 110.

The nerve cells of the *pars intermedia,* which connects the dorsal and ventral horns and lies opposite the gray commissure, may be divided broadly into two classes, the lateral and the middle cells, that occupy respectively the outer border and the more central area of this part of the gray matter of the spinal cord. A small number of nerve cells are usually to be found isolated within the white matter, outside but in the vicinity of the gray core. These outlying cells are regarded as elements, which have been dislocated from their usual position during the differentiation and growth of the white and gray matter of the cord. Similar displacement sometimes affects the cells of the spinal ganglia, which then may be encountered within the cord.

The nerve fibers within the gray matter contribute a considerable portion of the intricate ground work in which the nerve cells lie embedded. These processes are derived from neurons situated at the same, different or even remote levels. On emerging from the gray matter, the axons acquire a sheath of myelin, and become the medullated fibers of the adjacent white matter.

The Radicular Cells.—The efferent or motor neurons are the most conspicuous elements of the anterior horn (Fig. 57). They are stellate

and irregularly polygonal, the form of the individual cells being determined by the arrangement and shape of the dendritic processes. The diameter of the majority of these cells is between .075-.135 mm. In a general way, the size of the cells is in proportion to the length of the nerve fibers to which the cells give rise, the longer fibers coming from the larger cells. The radicular cells possess from three to ten dendrites, which divide dichotomously, becoming progressively more and more attenuated in passing toward the terminal arborizations.

The polygonal cell-body encloses a conspicuous round or oval *nucleus* measuring .010-.020 mm. in diameter and often somewhat eccentrically

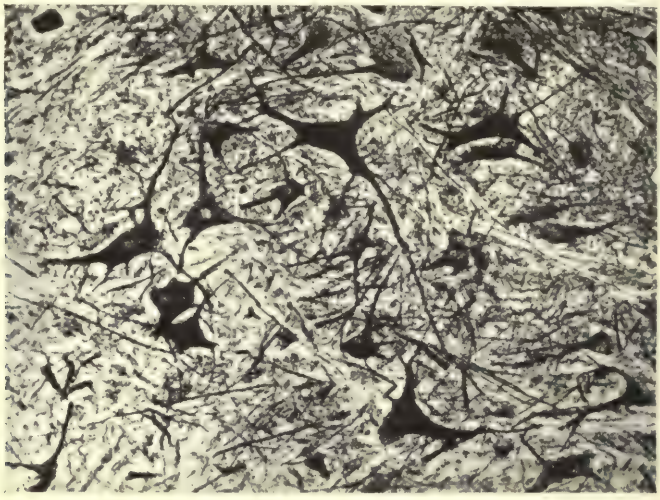

FIG. 57.—RADICULAR NERVE CELLS FROM ANTERIOR HORN. × 180.

placed, which is limited by a distinct nuclear membrane and traversed by an irregular reticulum of delicate fibrils, poor in chromatin. Within the nucleus is always a well-marked *nucleolus,* .003-.005 mm. in diameter, that exceptionally may be double. Accumulations of light brown *pigment granules* are usually present within the cytoplasm, particularly in the vicinity of the base of the axon, but never within the processes. During the early years of life the pigment is very sparingly developed, but it increases in amount as age advances. A membrane enclosing the cell-body is wanting.

Examined in indifferent media, the *cytoplasm* of the fresh and unstained cells appears homogeneous or faintly granular; only after treatment with certain fixing and staining reagents do the details of cell structure become visible. Among such details are irregular flakes or masses of deeply staining granules, the *Nissl* or *tigroid bodies.* The cytoplasm of the nerve cells may be regarded as made up of the stainable substance

or tigroid bodies, embedded within the surrounding unstainable, achromatic or ground substance. These tigroid bodies extend into the branched dendritic processes for a variable distance, but never invade the axon, nor the implantation cone, from which the axon arises.

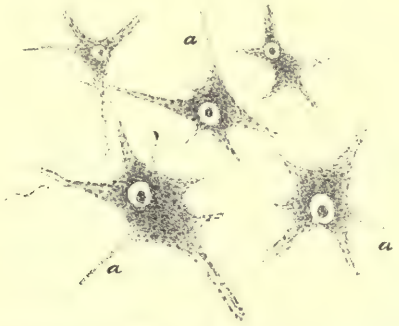

FIG. 58.—NERVE CELLS FROM ANTERIOR HORN, STAINED TO SHOW NISSL BODIES.
a. Axon. × 270.

The achromatic ground substance, lying between the tigroid bodies, after treatment with the newer staining methods, is seen to be permeated with delicate threads, the *neurofibrils*. While a fibrillar structure of the nerve cell is now universally accepted, the views as to the details and relations of the fibrillae are still at variance, especially as to whether the neurofibrils passing through the cell-body retain their independence, or take part, by anastomotic union, in the formation of an intricate network. All that can be affirmed with certainty is that from the dendrites the fibrils enter the cell-body, where they interlace in various intricate ways, and eventually leave the cell by entering the axon, which they traverse, reduced in number, as a compact bundle.

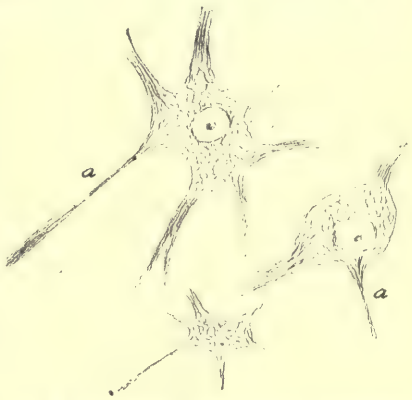

FIG. 59.—NERVE CELLS FROM ANTERIOR HORN, STAINED TO SHOW NEUROFIBRILS.
a. Axon. × 370.

The *axon* or *axis-cylinder process*, often difficult to identify, is usually represented by a single outgrowth, which arises from the implantation cone, a small clear elevation of the cell-body. Exceptionally, the axon arises from a dendrite near its root. Usually while still within the gray matter, the axon gives off one or two delicate processes, the *collaterals*, which, after a short horizontal course, ordinarily turn backward and eventually end in terminal arborizations.

The ultimate components of the axon are the neurofibrils, which are continued as a consolidated bundle along the axis-cylinder of the nerve fiber, probably embedded within a semifluid interfibrillar substance.

The Central Canal.—Where well represented, the central canal (*canalis centralis*), the remains of the once conspicuous neural tube, appears as a minute opening within the gray commissure, about .2 mm. in diameter, barely visible with the unaided eye. In the child, the canal extends the entire length of the spinal cord and, below, ends blindly in the upper half of the filum terminale. Above, it opens out into the lower end of the fourth ventricle, from which it is prolonged downward, through the closed lower part of the medulla oblongata, into the spinal cord. Within the conus medullaris, the central canal regularly exhibits an expansion, the *sinus terminalis,* that begins below the origin of the coccygeal nerve and extends caudally 8-10 mm. The obliteration of the central canal, complete in about 50 per cent of individuals beyond middle life, is to be regarded as a natural accompaniment of advancing age. It is effected by proliferation and displacement of the ependymal cells lining the canal, in conjunction with ingrowth of the surrounding neurogliar fibers (Weigert).

Fig. 60.—Central Canal of Young Cord, Lined with Ependymal Cells.

Surrounding these is the substantia gelatinosa centralis. × 90.

The *ependymal cells,* lining the central canal of the spinal cord, are the direct descendants of the embryonal supporting elements; they may, therefore, be regarded as specialized neuroglia cells. They appear as a single layer of pyramidal cells (Fig. 60), whose bases are directed towards the lumen of the canal and beset with cilia, and their pointed distal ends are prolonged into long delicate ependymal fibers.

The *substantia gelatinosa centralis* immediately surrounds the central canal of the spinal cord and consists of modified neuroglia, in which radial ependymal fibers are interwoven with circularly disposed neurogliar fibrillae. In contrast to the substantia gelatinosa Rolandi, which caps the apex of the posterior horn, the central substance contains few and small nervous elements.

The White Matter.—The predominating components of the white substance being the longitudinal nerve fibers, which pass for a longer or shorter distance up and down in the columns of the cord, in cross sections, the field between the gray core and the periphery is made up chiefly of the

closely set, transversely cut nerve fibers; in these the sectioned axis cylinders appear as deeply stained dots, that are surrounded by delicate annular striations, the expressions of the framework of the medullary coat. The nerve fibers of the cerebrospinal axis are devoid of neurilemma, the lack of this sheath being compensated by a slight condensation of the neuroglia, which penetrates between and holds together the individual fibers. The individual nerve fibers vary greatly in size, even in the same tract large and small fibers lying side by side. The smallest may be less than .005 mm. and the largest over .020 mm. in diameter.

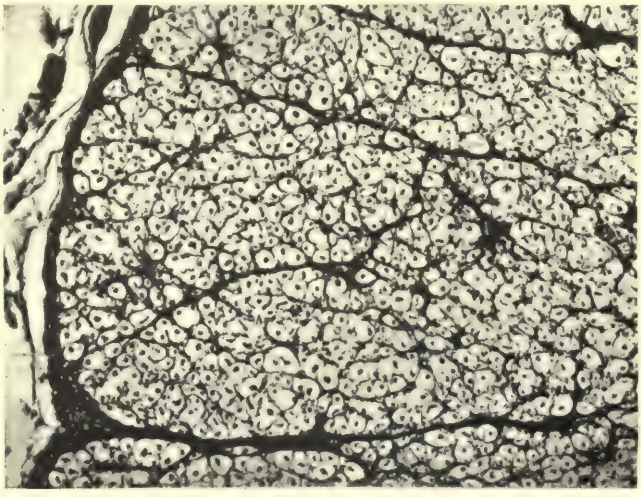

Fig. 61.—White Substance of Periphery of Cord, Showing Component Nerve Fibers in Cross Section and Supporting Neuroglia. × 165.

The surface neuroglia immediately beneath the pia mater is condensed into a tract, the *subpial layer*, that is devoid of nervous elements and forms the definite outer boundary of the cord. From the deeper surface of this layer, bundles of fibrillae penetrate between the subjacent nerve fibers to become lost in the general supporting ground work. At certain places, the bundles are replaced by robust septa by which the nerve fibers are imperfectly divided into groups or tracts, as seen in the partial subdivision of the posterior column into the gracile and cuneate fasciculi by the paramedian septum. The blood vessels that enter the nervous substance from the pia mater, accompanied by connective tissue, are surrounded by sheaths of neuroglia.

Structure of the Spinal Ganglia

The spinal ganglia are aggregations of the nerve cells presiding over the nutrition of the afferent or sensory fibers contained within the spinal nerves. The primary ganglion cells are derived from a special group of ectodermal elements, the ganglion crest, which grows laterally on either side of the neural tube and forms the developing ganglia. From the opposite poles of the immature nerve cell, processes grow out, on the one hand toward the periphery, to become the afferent nerve fiber, and on the other

toward the spinal cord, to become the centrally directed fiber of the posterior root.

The spinal ganglion, as seen in longitudinal section (Fig. 62), is invested by a dense fibrous sheath, directly prolonged from the dural covering of the posterior root and continuous with the epineurium of the afferent nerve. Immediately within this sheath, the ganglion cells are disposed as a fairly continuous layer, while the cells occupying the central portion of the ganglion are broken up into uncertain groups by the bundles of nerve fibers. The ganglion cells are surrounded by concentrically arranged layers of connective tissue plates, inside of which lies a homogeneous membrane, the *capsule,* provided on its inner surface with flat mantle cells.

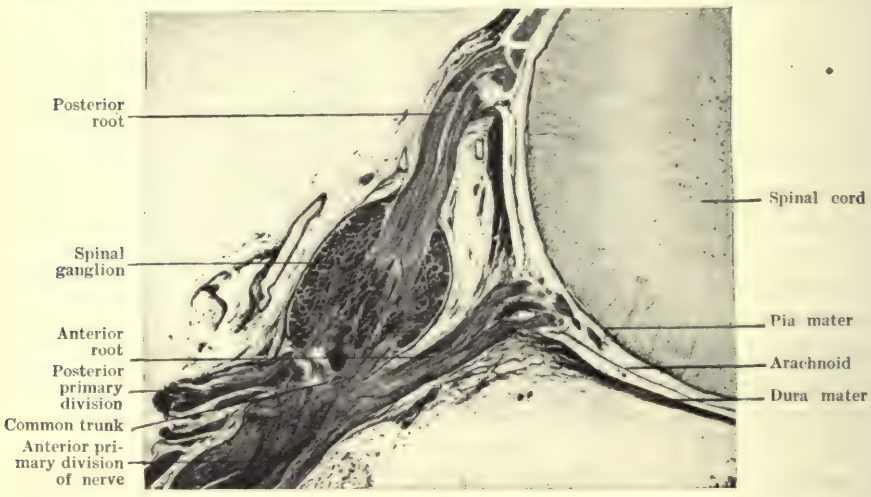

FIG. 62.—SECTION SHOWING PERIPHERY OF CORD, NERVE-ROOTS, SPINAL GANGLION AND PARTS OF SPINAL NERVE. × 17.

The ganglion cells are mostly irregularly oval or pyriform in shape, provided with a single process (axon), a vesicular nucleus with a distinct nucleolus, and a small amount of pigment. The cells vary greatly in size and in the arrangement and behavior of their processes. Based upon these peculiarities, Dogiel has described no less than eleven types of these cells; of these, according to Ranson, two fundamental groups are to be distinguished—the large and the small cells.

The *large cells* (Fig. 63) give off a single process (axon), which, after a longer or shorter, straight or convoluted course, divides dichotomously into a peripheral and a central (spinal) fiber. The axon is convoluted usually in the immediate vicinity of the cell, and, after piercing the capsule, acquires a coating of myelin and becomes a medullated fiber. The *small cells* (Fig. 64) and some of medium size give off axons, which seldom undergo complicated coiling, but pass more or less directly toward the

central nerve bundles of the ganglion. These axons are devoid of myelin and continue peripherally and centrally as nonmedullated fibers. The centrally directed fibers follow the posterior root and enter the spinal cord, some, according to Ranson, going to Lissauer's tract; their function is undetermined. It has long been known that, apparently, the number of posterior root fibers is much less than the number of cells in the ganglion. This discrepancy Ranson regards as explained by the fact that the fibers arising from the small cells are nonmedullated and, therefore, overlooked and uncounted. When all the posterior root fibers are counted, they correspond closely with the number of large and small cells of the ganglion.

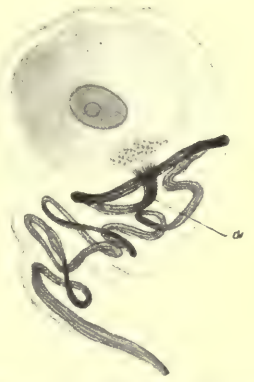

FIG. 63.—NERVE CELLS FROM SPINAL GANGLION; LARGE TYPE.
a. Axon. High magnification. (Dogiel.)

FIBER TRACTS OF THE WHITE MATTER

Although microscopical examination of ordinary transverse sections of the spinal cord affords slight indication of a subdivision of the columns of white matter into areas corresponding with definite fiber tracts, the combined evidence of anatomical, embryological, pathological and experimental investigation establishes the existence of a number of such paths of conduction. With few exceptions, they are, however, without sharp boundaries and ill-defined, adjoining tracts often overlapping. In addition to paths of conduction for its function as a center for independent reflex impulses in response to external stimuli, the cord contains tracts that connect it with the brain, as well as those that bring the various levels of the cord itself into association.

FIG. 64.—NERVE CELLS FROM SPINAL GANGLION; SMALL TYPE.
High magnification. (Ranson.)

Since it is impossible to distinguish between the three classes of fibers by mere inspection of sections of the adult normal spinal cord, advantage is taken of other means, by which the recognition of individual tracts is possible. Such means include chiefly the experimental and embryological methods.

The *experimental method* depends upon the fact discovered by Walier, more than half a century ago, that when the continuity of a nerve fiber is destroyed, either by a pathological process or by the experimenter, the portion of the fiber beyond the break, and, therefore, isolated from the presiding nerve cell, undergoes secondary degeneration, while the portion re-

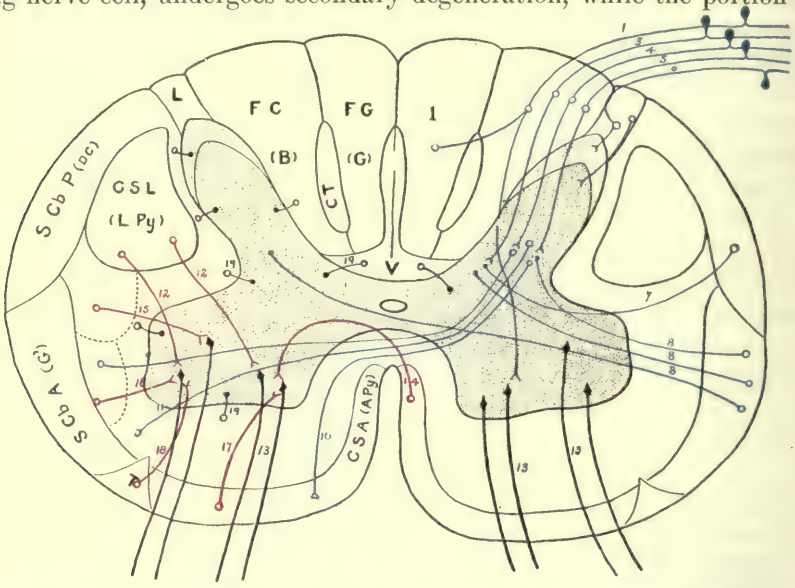

FIG. 65.—DIAGRAM SHOWING ORIGIN AND RELATION OF COMPONENTS OF PRINCIPAL FIBER-SYSTEMS OF SPINAL CORD.

Blue are afferent and red are efferent fibers. FG, (G), fasciculus gracilis or Goll's tract; FC, (B), fasciculus cuneatus or Burdach's tract; L, Lissauer's marginal zone; V, ventral field; CT, comma tract; SCbP, (DC), fasciculus spino-cerebellaris posterior or direct cerebellar tract; SCbA, (G'), fasciculus spino-cerebellaris anterior or Gowers' tract; CSL, (LPy), fasciculus cerebro-spinalis lateralis or lateral pyramidal tract; CSA, (APy), fasciculus cerebro-spinalis anterior or anterior pyramidal tract; T, fasciculus olivo-spinalis or triangular bundle; 1-5, posterior root-fibers proceeding from cells of spinal ganglion and entering posterior column; (°) indicates that fibers run vertically; 6 fibers entering marginal zone; 7 fibers of direct cerebellar tract from cells of Clarke's column; 8, fibers of Gowers' tract; 9, 10, spino-thalamic fibers; 11, spino-tectal fibers; 12, 14, lateral and anterior cerebro-spinal or pyramidal fibers; 13, anterior root fibers from radicular cells; 15, rubro-spinal fibers; 16, tecto-spinal fibers; 17, vestibulo-spinal fibers; 18, olivo-spinal fibers; 19, association fibers.

maining connected with the cell usually undergoes little or no change. In this manner, by study of consecutive sections, much valuable information has been gained as to the origin, course, destination and function of many fiber tracts within the central nervous system.

The *embryological method* is based on the fact that the nerve fibers of the central nervous system do not acquire their medullary coat all at the same time. Taking advantage of this variation, upon staining sections of embryonal material by methods that color especially the medullary substance, it is possible to demonstrate certain fiber tracts in the fetal cord

with great clearness, since only those are stained in which the myelin is already formed.

The accompanying schematic figure must be regarded as showing only the general relations of the most important paths of the spinal cord, and not as representing the actual size and form of the fiber tracts. Moreover, it must be understood, that the definite boundaries given the tract in such diagrammatic representations do not exist in nature, since the fibers of adjacent tracts in many cases overlap, or sometimes intermingle, so that the same area may be shared by strands belonging to different fiber systems (Fig. 65).

Fiber Tracts of the Posterior Column.—The posterior column of white matter is subdivided by the paramedian septum into two parts; of these the median one is the more slender and is the *fasciculus gracilis,* or *tract of Goll,* and the lateral one is the *fasciculus cuneatus,* or *tract of Burdach.* These tracts, being largely made up of fibers entering by the posterior roots, the general relations and behavior of these fibers must be considered in order to understand the composition of the posterior columns, as well as that of certain secondary paths.

FIG. 66.—SECTION OF SPINAL CORD AT LEVEL OF SECOND CERVICAL SEGMENT. × 4.2.

All afferent impulses enter the cord by way of the posterior roots. The root fibers reach the surface of the cord along the posterolateral sulcus as a compact bundle, which, just about as it penetrates the subpial layer to enter the white matter, presents a constriction. This constriction depends upon the loss of the connective tissue sheaths and indicates the place at which the root fibers lose their peripheral character and assume that of central fibers.

The root fibers enter the posterior column close to the tip of the posterior horn. On gaining the white matter, they undergo a Y-like division, each fiber dividing into a descending and an ascending branch. The former, after a short vertical course, equal in length to the height of from one to two cord-segments, turns at right angles and enters the gray matter to end around some nerve cell. The ascending branch may have a course only slightly longer (from one to four segments) than that of the lower branch, in which case its behavior is similar to that described—bends sharply inward to end in relation to some cell. On the other hand, many fibers of the gracile and cuneate fasciculi possess ascending branches which do not end around the cells of the cord, but have their terminations within

the medulla oblongata. A few fibers present a modification of the usual arrangement, in that the division into descending and ascending branches does not take place until after the fiber has entered the gray matter.

During their longitudinal course, both branches, but particularly the descending and the proximal part of the ascending, give off collaterals, which pass horizontally into the gray matter and to the posterior horn cells. In addition to these short collaterals destined for the posterior horn, the fibers of the long posterior tracts give off long *reflex collaterals,* that pursue a sigmoid course, traversing the substantia gelatinosa Rolandi, the other parts of the dorsal horn and the intermediate gray substance, to end in arborizations around the root cells of the anterior cornu, thus establishing simple reflex paths, by which sensory impulses transmitted by the posterior roots directly impress the motor neurons.

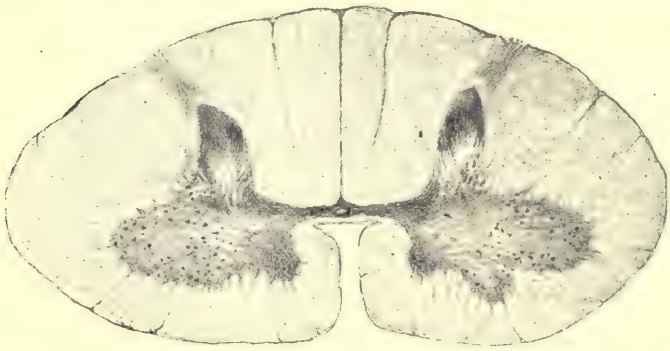

FIG. 67.—SECTION OF SPINAL CORD AT LEVEL OF EIGHTH CERVICAL SEGMENT. × 4.2.

The fibers constituting the ventral part of the posterior root, small in diameter, enter the field immediately over the apex of the dorsal cornu, known as *Lissauer's marginal zone.* Within this area, the fibers undergo the usual division into ascending and descending branches, which, after a short course, enter the gray matter and end about the cells of the posterior horn, especially those of the substantia gelatinosa. Ranson has shown that the posterior roots contain, along with the medullated fibers, many nonmedullated axons derived from the small cells of the spinal ganglia; further, that these nonmedullated fibers form the chief constituents of Lissauer's tract. Since they seem to enter the substantia gelatinosa, this area of gray matter may be the reception nucleus for these nonmedullated fibers (Ranson).

The fibers of the *long posterior tracts,* on entering the posterior column, divide into descending and ascending branches. The former run downward for a short distance and give off collaterals, some of which are long reflex collaterals to the anterior horn cells. The ascending branches also send off collaterals, from their lower part, but, instead of turning into the gray matter to end around the cells of the posterior horn, they continue their upward course, traverse the entire extent of the cord lying above the level of their entrance, and pass up into the medulla oblongata,

until they reach the masses of gray matter known as the *nucleus gracilis* and *nucleus cuneatus* where they end. These long fibers, therefore, have their reception nuclei not within the spinal cord, but within the posterior column nuclei, as they are often called, within the medulla oblongata. The long fibers terminating in the gracile and cuneate nuclei convey impressions of various kinds; some carry impulses of "muscle-sense," others impulses giving rise to common sensation. The cells of the reception nuclei sort and distribute the impulses along new paths. Those concerned in "muscle-sense" are carried by axons to the cerebellum, conveying to that important center information used in maintaining coördination; while those concerned in common sensation cross at the sensory decussation in the medulla oblongata and, by way of the great sensory pathway, the *mesial fillet,* are carried to the thalamus, eventually reaching the cerebral cortex. The descending branches of the long fibers are, for the most part, collected into a definite area and form the chief constituents of the small field, lying between the tracts of Goll and of Burdach, which, from its shape in cross sections, is known as the *comma tract* of Schultze.

On entering the posterior column, the long fibers first lie within the fasciculus cuneatus, near the dorsal cornu. As each successive higher root enters the cord, its long fibers take up a similar position. It follows that, with the augmenting volume of the cuneate strand due to the increments of fibers brought in by the successive roots, the fibers that entered at lower levels are displaced mesially and, while first lying within the fasciculus cuneatus, are gradually pushed into the fasciculus gracilis. The latter, therefore, contains the longest fibers, those entering the cord lowest lying nearest the midline; on the contrary, the fibers entering the upper part of the cord, from the fourth thoracic nerve up, retain their position within the fasciculus cuneatus.

The lateral group of root fibers entering the fasciculus cuneatus keep near the dorsal cornu, into which, after a short longitudinal course, the ascending and descending branches turn, to end in relation with the nerve cells of the posterior gray substance. From these latter cells, axons pass to the white matter and turn toward the brain as constituents of the ascending paths, which are considered under the tracts of the anterolateral column.

After eliminating the field occupied by the long posterior and other root fibers, there remains a small part of the posterior column unaccounted for. This area collectively constitutes the *fasciculus posterior proprius* and includes certain more or less definite fields, which, however, vary at different levels of the cord. Immediately behind the commissure and the adjoining dorsomedian borders of the gray horns, lies a crescentic area, the *ventral field,* which is continued dorsally along either side of the posterior median septum. In the thoracic cord, this extension is represented by a narrow zone along the midline; in the upper lumbar cord, the zone

is more marked, while lower, it acquires a planoconvex outline, the areas of the two sides together forming the *oval field* (dorsomedian sacral bundle). In the upper sacral region, this field occupies an extreme dorsal position, against the periphery of the cord, where it appears as a narrow wedge, the *triangular field.*

The areas collectively forming the fasciculus posterior proprius are occupied chiefly by the ascending and descending branches of small cells, which link together the segments of the cord; they constitute, therefore, important *association paths.* The small association cells lie within the gray matter of the posterior horn, to a large extent within the substantia gelatinosa, from which they send axons into the posterior column that divide into ascending and descending branches. After a longer or shorter course within the white substance, the branches bend centrally, enter the gray matter and end around other cells of the posterior horn. Some of the association fibers are short, linking together adjoining segments; others are longer and extend between more widely separated levels. Although chiefly composed of the axons of association cells, in many places the fasciculus proprius contains also fibers coming from the long tracts, principally the descending branches.

FIG. 68.—SECTION OF SPINAL CORD AT LEVEL OF SECOND THORACIC SEGMENT. × 4.2.

Fiber Tracts of the Anterolateral Column.—The *posterior spinocerebellar fasciculus,* or the *direct cerebellar tract,* takes origin from the cells of Clarke's column or nucleus dorsalis. It occupies a narrow peripherally situated field, lying in front of Lissauer's zone and between the lateral pyramidal tract and the surface of the cord, and extends forward almost half way to the anterior root. The tract begins somewhere between the second and third lumbar segment and rapidly increases in size in the upper lumbar and lower thoracic cord, above which level its augmentation is gradual as far as the lower cervical nerves. Higher, the outline of the tract becomes obscured by reason of the intermingling of its fibers with those of the lateral pyramidal path.

The posterior root fibers conveying impulses to the cells of Clarke's column traverse the fasciculus cuneatus, enter the median side of the posterior horn and end around the cells of the nucleus. During this course they describe gentle sigmoid curves and terminate in relation with cells that lie almost at the same level, or only a little higher than that of their entrance into the cord. Starting as the peripherally directed axons

of the large cells of Clarke's column, and, possibly, to some extent also of cells of the intermediate gray matter, the fibers pass horizontally through the intervening gray and white substance to the peripheral field. On gaining this they turn toward the brain and continue up the superficial portion of the cord and medulla oblongata to the inferior cerebellar peduncle, by which arm they are conveyed to the central lobe of the cerebellum, some fibers decussating in the worm. As indicated by its older name, the tract establishes direct communication between the spinal cord and the centers for coördination.

The Anterior Spinocerebellar Fasciculus.—This tract, or the *tract of Gowers,* begins in the lumbar cord, one or two segments lower than the direct cerebellar tract, and occupies the ventral half of the peripheral field in the lateral column, immediately in front of the direct cerebellar tract, being somewhat broader behind than before. Its fibers are the axons of the middle cells of the pars intermedia and also of the cells of Clarke's column; some fibers originate from the cells of the opposite side. The fibers pass laterally to their superficial field and turn toward the brain. The path by which they gain the cerebellum is less direct than that of the posterior spinocerebellar tract, since, on reaching the brain stem, they ascend through the medulla oblongata and the pons to the superior cerebellar peduncle, where they turn backward into the superior medullary velum, finally to end chiefly within the worm of the cerebellum. From studies of degeneration it would appear that some of the fibers of the tract do not extend to the cerebellum, but end in the gray matter of the cervical region of the cord (Obersteiner).

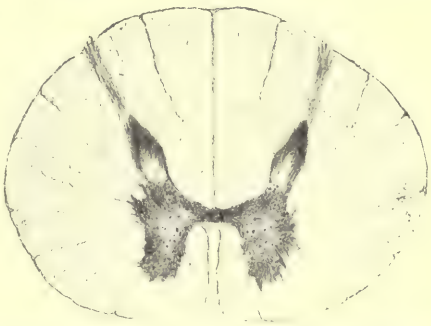

Fig. 69.—Section of Spinal Cord at Level of Sixth Thoracic Segment. × 4.2.

The Spinothalamic Tract.—Although relatively inconspicuous, this tract is functionally of great importance as establishing a direct sensory pathway between the spinal cord and the cerebrum. The fibers forming the tract are axons of cells within the median and deeper parts of the dorsal horn of the opposite side, the crossing of the sensory fibers in this instance taking place within the cord. Traced from their origin, the fibers traverse the gray matter, cross to the opposite side by way of the anterior white commissure, and sweep through the ventral horn of that side to reach the lateral column. The field occupied by most of the fibers of the tract lies mesial to the ventral part of Gowers' tract, but it is not sharply defined, since the fibers of the two paths intermingle. After bending toward the brain, the fibers ascend into the medulla oblongata and

take a position close to the lateral border of the mesial fillet, which, in a general way, they follow to the thalamus. While the major part of the fibers of the tract occupy the lateral column in the position just described, a portion of the fibers, after crossing the midline, curves ventrally and forms the *anterior spinothalamic fasciculus,* which occupies a superficial area along the ventral border of the anterior column, the fibers intermingling and sharing the field with those of the vestibulospinal bundle.

The Spinotectal Fasciculus.—This tract resembles the spinothalamic tract in origin and in crossing to the opposite side of the cord; its position is more ventral, lying mesial to and overlapping the pointed extremity of Gowers' tract. Instead of terminating above in the thalamus, its fibers end in relation with the nuclei of the corpora quadrigemina.

All the long paths so far considered convey impulses toward the brain and are, therefore, *ascending tracts;* moreover, all, with the exception of the long posterior paths, are the axons of neurons situated within the spinal cord, their fibers constituting the second links in the pathways conveying impulses from the periphery to the brain. Next to consider, are the important *descending tracts* by which impulses originating in the higher levels are transmitted to the cells of the spinal cord.

The Corticospinal Tracts.—These are the axons of neurons situated within the motor areas of the cerebral cortex. These axons pass through the corona radiata, internal capsule and the ventral part of the brain stem—cerebral peduncle, pons and medulla oblongata. On entering the latter, the corticospinal fibers are collected into a compact bundle, which produces a superficial tapering elevation, bounded mesially by the anterior median fissure; this elevation is the pyramid and its component fibers constitute the *pyramidal tract.* On reaching the lower end of the medulla oblongata, some eighty-five per cent of the corticospinal fibers undergo decussation, leaving their median position to cross to the opposite side and assume a lateral and deeper situation in the lateral column of the spinal cord. The remainder of the pyramidal fibers continue into the cord on the same side, taking up their position in the anterior column along the anterior median sulcus.

The Lateral Cerebrospinal Fasciculus.—This tract, also known as the *lateral pyramidal tract,* occupies a well-defined area lying between the lateral border of the posterior horn and direct cerebellar tract and extending ventrally, where best developed, to a line drawn through the dorsal border of the gray commissure. In its descent, the area of the tract diminishes, particularly at the enlargements of the cord where the limb nerves arise, but the path is recognizable, as a small triangular field, as far as the third or fourth sacral segment. From the preceding statements, it is evident that the fibers of the tract are the axons of the cortical neurons, which have crossed the pyramidal decussation and entered the field in the lateral column. After descending the cord to the level required

by their relations to the muscular system, the fibers cut ventrally through the intervening white and gray matter to end around the root cells of the anterior horn. While this is the destination of the main fibers, a certain number of collaterals end in relation with cells in the posterior horn. In places, as in the cervical region, the lateral pyramidal field contains fibers belonging to other and ascending paths; on the other hand, a few fibers of this tract are scattered in other parts of the lateral column. It has been demonstrated by degenerations, that a small number of lateral pyramidal fibers do not cross, but descend on the same side.

The Anterior Cerebrospinal Fasciculus.—This direct (or uncrossed) *pyramidal tract* is formed by the pyramidal fibers that do not decussate in the medulla oblongata, but pass into the cord on the same side. The tract appears as a narrow zone, bordering the anterior median fissure, and is traceable to the middle of the thoracic cord, occasional fibers having been followed to the sacral region. After entering the tract, the fibers, at the appropriate levels, cross by way of the white commissure to the opposite anterior horn to end around the ventral root cells. It will be noted that the terms "crossed" and "uncrossed" apply to the behavior of the pyramidal fibers only in the medulla, since virtually all the fibers undergo decussation before gaining their objective spinal cells. Some fibers, however, do not undergo the usual crossing but end around the anterior horn cells of the same side. These fibers, *tractus pyramidalis ventrolateralis,* occupy a superficial position in the anterior column, in the midst of the peripheral ventral field containing the vestibulospinal bundle.

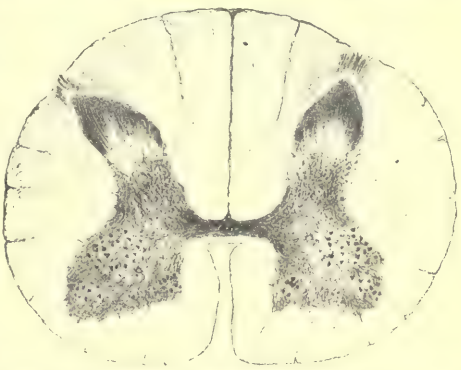

Fig. 70.—Section of Spinal Cord at Level of Third Lumbar Segment. × 4.2.

In addition to the pyramidal tracts, other long descending paths are located in the anterolateral column, conveying reflex and coördinating impulses from the nuclei of the brain stem to the root cells of the cord. These paths are, for the most part, composed of fibers that do not form compact bundles and are ill-defined.

The Rubrospinal Fasciculus.—This tract, also known as *Monakow's bundle,* occupies the field immediately ventral to the pyramidal tract and medial to the tract of Gowers. It consists of descending fibers, the crossed axons from the cells of the red nucleus within the tegmental part of the midbrain, underlying the superior corpora quadrigemina. Since the red nucleus is a relay station along the path conveying efferent impulses from

the cerebellum, the rubrospinal fasciculus is of importance as transmitting to the spinal cord impulses used in coördination. On reaching the appropriate level of the cord, the fibers pass ventromesially and turn into the gray matter to end around the anterior horn cells which they influence.

The Tectospinal Fasciculus.—Sometimes called the ventral longitudinal bundle, this tract derives its fibers from the nuclei of the superior quadrigeminal bodies. These fibers cross in the tegmental decussation of Meynert, descend into the spinal cord, partly within the lateral column, as a poorly defined bundle intermingling with the rubrospinal and Gowers' tracts, and partly within the anterior column, as one of the constituents of the superficial sulcomarginal area. On gaining the appropriate level, the fibers turn into the anterior horn and end in arborizations around the ventral root cells.

Fig. 71.—Section of Spinal Cord at Level of Fifth Lumbar Segment. × 4.2.

The vestibulospinal fasciculus arises from cells of the lateral vestibular or Deiters' nucleus in the medulla oblongata. On reaching the spinal cord, the fibers descend, loosely grouped, within the superficial and ventral part of the anterior column, sharing the sulcomarginal field, from which they bend centrally to enter the anterior cornu and end around the root cells. Since Deiters' nucleus is an important relay station for impulses gathered from the vestibular part of the internal ear, as well as from the cerebellum, it is evident that the vestibulospinal fibers carry to the cord impulses aiding in maintaining coördination. A similar intraspinal course is described for the *tegmentospinal fasciculus,* which proceeds from the cells of the tegmental region.

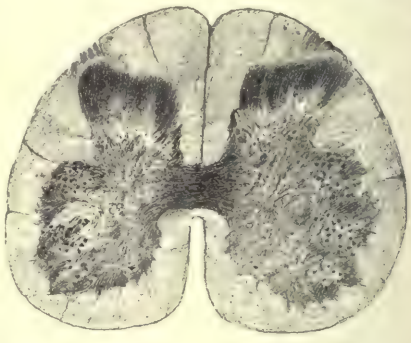

Fig. 72.—Section of Spinal Cord at Level of Second Sacral Segment. × 4.2.

The Olivospinal Fasciculus.—This fasciculus, known also as *Helweg's bundle,* descends from the cells of the inferior olivary nucleus, within a tract usually of triangular outline, lying between the ventral end

of Gowers' tract and the emerging anterior root fibers. As a distinct bundle, the fibers are traceable as low as the lower cervical or upper thoracic cord. Although descending fibers have positively been demonstrated within this tract, it is possible that the field is shared by fibers conveying impulses in the opposite direction; hence the name, spino-olivary fasciculus, sometimes applied to this path.

The Fasciculus Anterolateralis Proprius.—This fasciculus, or *anterolateral ground-bundle,* comprises the zone bounded by the gray matter mesially and uncertainly by the long ascending tracts peripherally. As noted in connection with the posterior column, so in the ventrolateral column, the area under discussion is made up in large part of the association paths linking together the different segments of the cord. The portion of the field next the gray matter is devoted, in a general way, to the shorter association fibers, passing from cells of one level, up and down, and returning to the gray matter of adjacent levels; while the more peripheral part of the field contains the longer association fibers, bringing into relation levels farther separated.

Long Tracts of The Spinal Cord

Posterior Column
- Ascending Tracts
  - Fasciculus gracilis (Goll)
  - Fasciculus cuneatus (Burdach)

Lateral Column
- Ascending Tracts
  - Fasciculus spinocerebellaris dorsalis (Direct cerebellar)
  - Fasciculus spinocerebellaris ventralis (Gowers')
  - Fasciculus spinothalamicus
  - Fasciculus spinotectalis
  - Fasciculus spino-olivarius
- Descending Tracts
  - Fasciculus cerebrospinalis lateralis (Lateral or crossed pyramidal)
  - Fasciculus rubrospinalis (Monakow's bundle)
  - Fasciculus tectospinalis
  - Fasciculus olivospinalis

Anterior Column
- Ascending Tracts
  - Fasciculus spinothalamicus anterior
- Descending Tracts
  - Fasciculus cerebrospinalis anterior (Direct or uncrossed pyramidal)
  - Fasciculus tectospinalis
  - Fasciculus tegmentospinalis
  - Fasciculus vestibulospinalis

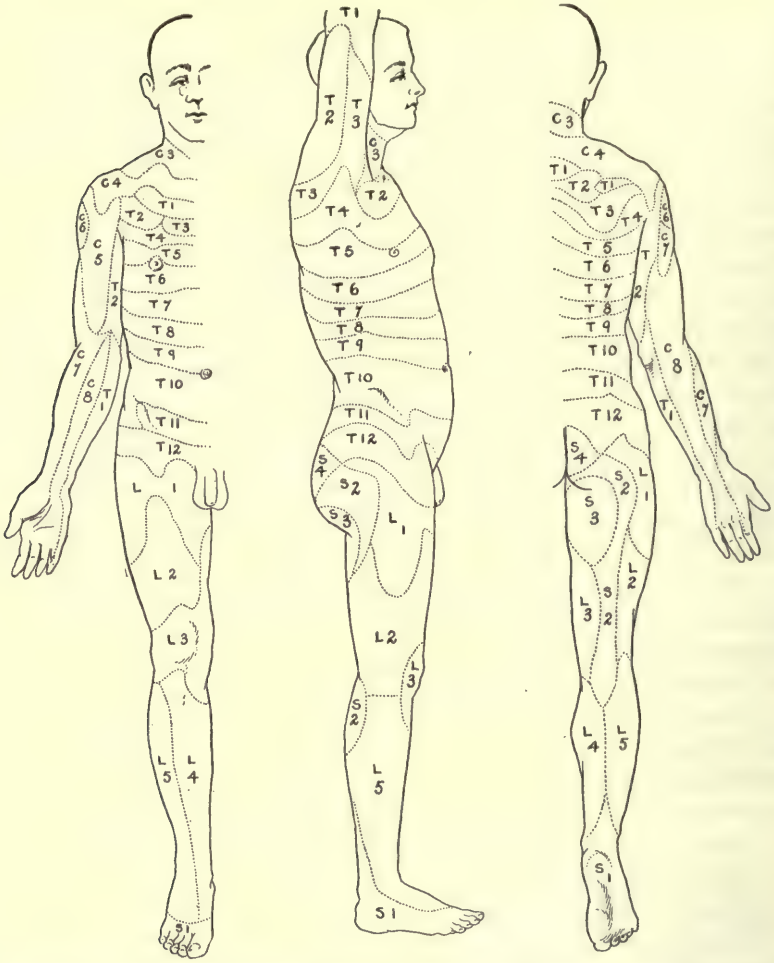

FIG. 73.—SEGMENTAL CUTANEOUS AREAS, BASED ON CLINICAL AND PATHOLOGICAL OBSERVATIONS.

Letters and numerals indicate related cord-segments. (Modified from Head.)

DEVELOPMENT OF THE SPINAL CORD

The first suggestion of the central nervous system appears very early in embryonic life as a shallow groove in an axial thickening of the ectoderm, the *neural plate,* bounded laterally by rapidly growing ridges, the *neural folds.* By the upward growth of these folds the shallow groove is converted into a deep furrow, which, by the approximation and final fusion of the folds, becomes a closed tube, the *neural canal;* after separation from the surface ectoderm, the tube becomes the representative of the cerebrospinal axis. The separation of the neural tube from the surface

ectoderm is accomplished by the ingrowth of the mesoderm contributed by the sclerotomes (page 24), which surrounds ventrally and laterally the neural tube and, meeting behind, constitutes the membrana reuniens

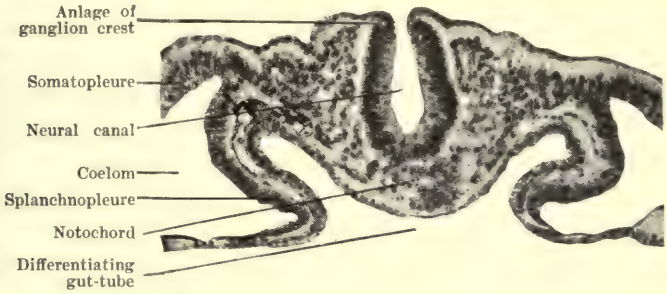

FIG. 74.—TRANSVERSE SECTION OF EARLY EMBRYO, WITH CLOSING NEURAL CANAL. × 170.

posterior. Arrested development of this membrane is a fundamental factor in the production of the graver forms of spina bifida, since imperfect

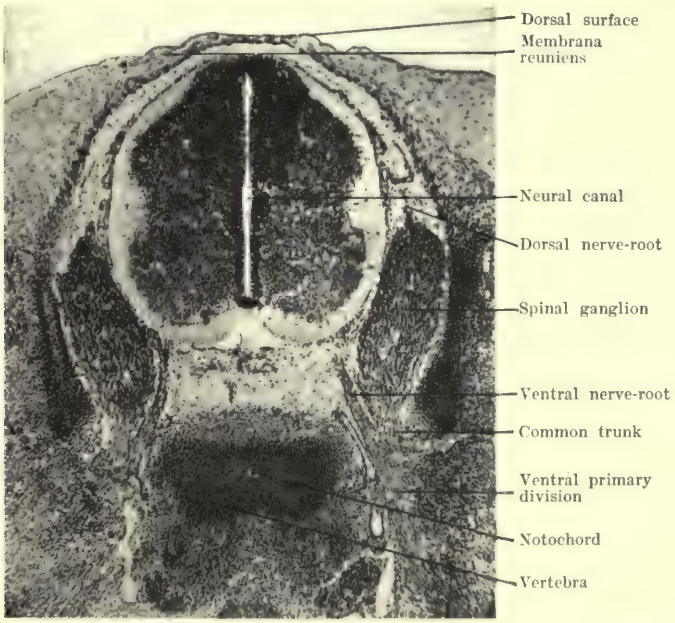

FIG. 75.—DORSAL PART OF SECTION OF EMBRYO, SHOWING DEVELOPING CORD, SPINAL GANGLIA AND NERVE-ROOTS. × 40.

formation of the membranous vertebrae and incomplete closure of the neural tube may follow.

Just over the lips of the approximating neural folds, the ectoderm

differentiates into special groups of cells that, when the neural folds meet, give rise to a wedge-shaped mass of cells, the neural or *ganglion crest,* from which the spinal ganglia and the afferent nerves are ultimately developed.

At first, the wall of the neural canal consists of a few layers of ill-defined cells, many of those next to the lumen of the tube being actively engaged in mitosis. As the result of this proliferation, the wall thickens, the component cells losing their outlines and forming a syncytium. Differentiation soon suggests three zones—an inner *germinal zone,* rich in dividing cells; an intermediate nuclear or *mantle zone,* containing many nuclei; and an outer reticular or *marginal zone.*

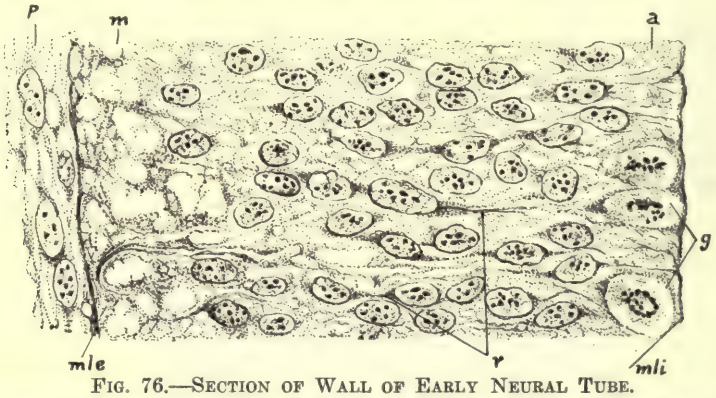

FIG. 76.—SECTION OF WALL OF EARLY NEURAL TUBE.

a, Germinal or ependymal zone; *g,* dividing cells next lumen of canal; *m,* marginal zone; *r,* radial filaments appearing within mantle zone; *mli, mle,* internal and external limiting membrane; *p,* pial tissue. × 700. (Hardesty.)

The cells of the mantle zone for a time are apparently indifferent; shortly, however, some of its elements become pear-shaped with the pointed end directed peripherally, and, since they become the primary nerve cells, are the *neuroblasts,* while other elements become elongated and, giving rise to the supporting neuroglia, are the *spongioblasts.*

The elements destined to become nerve cells are distinguished from the spongioblasts by their pyriform contour and the deeply staining process which grows from the pointed end. This process is the axon which grows peripherally, passes beyond the spinal cord as a constituent of the ventral root and extends into the surrounding mesoderm as a peripheral nerve fiber. For a considerable time, the axon alone is present, but later the dendritic processes grow out from the young cell in various directions.

The posterior root fibers have a different history, since, as already mentioned, they are outgrowths from the immature spinal ganglia. The latter are derived from the cells of the neural crest, which derivatives take up a lateral position on either side of the young cord and form the

oval masses of the developing ganglia (Fig. 75). For a time the ganglion cells are fusiform bipolar elements, a process passing off from each of the two opposite poles of the cell. During subsequent growth the cell manifests an unilateral expansion, consequently the two processes approach and finally become attached to the cell by a single stem, from which, in the now unipolar cell, a peripherally and a centrally directed process is given off. While the latter grows into the spinal cord, as a posterior root fiber, the former grows toward the periphery, to form a path for the conveyance of afferent impulses. It is evident, therefore, that

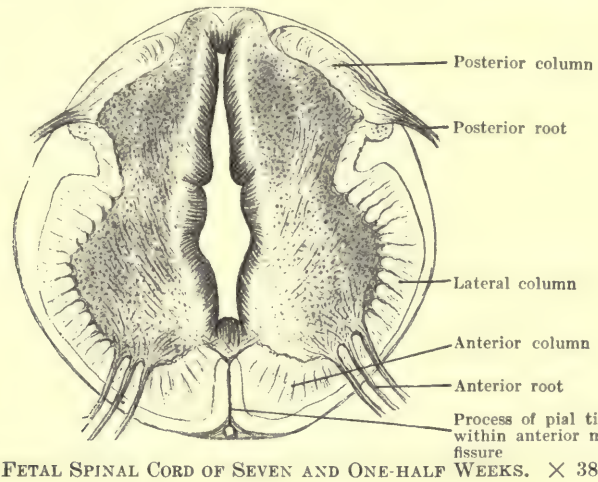

FIG. 77.—SECTION OF FETAL SPINAL CORD OF SEVEN AND ONE-HALF WEEKS. × 38. (His.)

all the important parts of the nervous system—cells, processes and neuroglia—are the direct derivatives of the ectoderm. On the other hand, the blood vessels, which secondarily invade the growing nervous centers, are of mesodermal origin, as is, of course, the connective tissue accompanying the blood vessels.

Shortly after the conversion of the groove into a closed tube, the wall of the neural canal exhibits a differentiation into three regions. These are the relatively thick lateral areas and the thin ventral and dorsal bridges connecting the side walls, the floor- and the roof-plate. By the fourth week of intrauterine life, the lumen of the canal is reduced to a narrow oval opening; subsequently, the dorsal part disappears, while the ventral part persists, to become the central canal of the cord. Meanwhile, the walls of the neural tube rapidly thicken, not only by differentiation and growth of the gray substance, but also by the addition of a peripheral zone of white matter. The latter is contributed by the axons of the neuroblasts within the cord and by those that grow into the cord from the cells of the spinal ganglia and of the brain.

As the ventral cornua and columns become more voluminous, they

bulge forward on either side of the midline and thus convert the shallow furrow beneath the floor-plate into a deepening sulcus, later the anterior median fissure. The production of the posterior median septum is effected by the approximation and fusion of the boundaries of the posterior half of the tube in conjunction with the outgrowth and gradual elongation of the ependymal cells.

The membranes of the spinal cord are differentiated from the sheath of the mesoderm, contributed by the scleratomes, which becomes enclosed with the cord within the developing vertebral canal. The penetrating

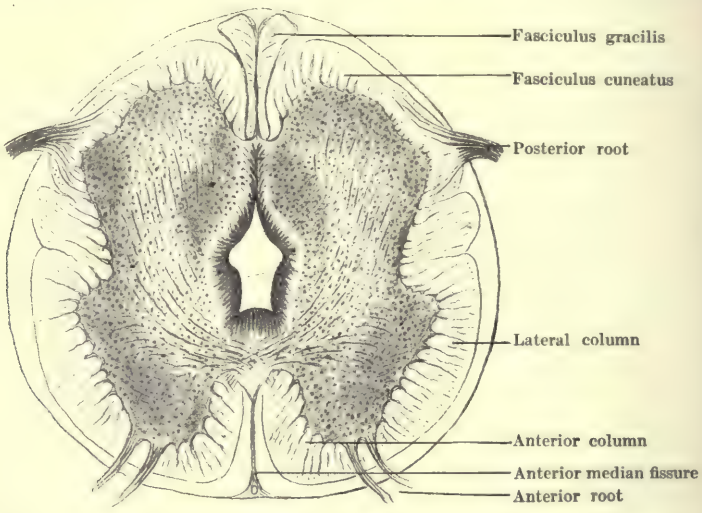

FIG. 78.—SECTION OF FETAL SPINAL CORD OF THIRD MONTH. × 24. (His.)

vessels carry along with them a sheath of the mesodermic tissue, which aids the ectodermic neuroglia in dividing the white matter into the larger areas.

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CHAPTER II

NORMAL AND PATHOLOGICAL PHYSIOLOGY OF THE SPINAL CORD

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THE NATURE AND MECHANISM OF NERVE IMPULSE

Two of the most fundamental questions in physiology—the nature of nerve impulse and of inhibition—though for years the target for philosophy and speculation, remain unanswered. The physiologist, therefore, is forced to postulate his arguments on a foundation anything but secure, and from time to time alters or reverses dicta previously considered permanent, as new discoveries demonstrate his premises untenable.

The idea of a past generation that the nerve impulse was an electric current lasted only until careful measurements of rate of flow seemed to render this concept absurd. That a nerve impulse can be initiated by electric stimulation is beyond question. The changing electrical potential in a nerve through which an impulse is passing by virtue of electric stimulation may easily be proven by the capillary electrometer or string galvanometer. The identity of this variation, in the case of experimental stimulation, with the normal condition has been conclusively shown by experiments in which the variations of the normally functionating pneumogastric nerve have been recorded photographically by means of a string galvanometer. To-day the opinion of physiologists is practically unanimous that the nerve impulse is not an electric current, though recently some experimental work has been performed to show analogy between the rapidity of flow of an electric current of minute strength through a great resistance and that of a nerve impulse.

Let us, therefore, assume that through a chemical disturbance in the arrangement of the molecules in a nerve cell body an unstable condition is effected, which disturbance is transmitted through the axon of the cell to its most peripheral part where in turn it either sets up this disturbance in equilibrium in an end organ or passes it on to another cell body. This concept is not inconsistent with positive and negative variation nor with a comparatively slow rate of flow; nor is it inconsistent either from the standpoint of the various forms of stimulation used in the physiological laboratory or the fact that the initial stimulus may act, as in the sensory system, primarily on an end-organ.

The passage of a stimulus from one neuron to another has, since the advent of Waldeyer's neuron concept, received two possible explanations: (1) The axon of one neuron may break up into a fine arborization, the ends of these fine fibers coming in contact with like arborizations of the dendritic processes of the second nerve cell. (2) The fine arborizations of the axon of the first nerve cell may be applied to the cell body of the second cell, a condition spoken of histologically as concrescence. These two forms of junction are in no way incompatible with Sherrington's idea of synapse. At this junction there may well be a retardation in rate of flow of impulse. At this synapse the mechanism may be particularly vulnerable as has been seen in experiments on the sympathetic nervous system with nicotin.

The more delicate methods of histological technic, as developed particularly by Bielchowski, have demonstrated neurofibril structure in the body, dendrites and axon of the nerve cell, and it is held by some that, although the neurons are distinct links in the nervous chain, the neurofibrils are continuous from one cell to another and are moreover the special conducting fibers of the system. This would, of course, throw great doubt on the theory of synapse were it conclusively proven. But many who believe in the functional importance of neurofibrils do not hold to the theory of continuity; and there are many who doubt the presence of neurofibrils in living nervous tissue, holding that they are in all likelihood condensations due to the peculiar technic of the staining process. Therefore, until we are in possession of more definite knowledge, it were well to hold to the theory of axon-dendrite and concrescence synapse and consider the neuron as the elementary unit of the nervous system.

SPECIFICITY IN FUNCTION OF SENSORY NEURON

The question naturally arises: Are the neurons forming given fiber tracts in the spinal cord or connecting with these tracts in the peripheral nervous system specific for any given form of stimulus? We know that a certain neuron conducts impulses of temperature, another impulses of pain, while a third transmits tactile impressions, and a fourth somatic motor stimuli. In fact, modern neurology divides the afferent and efferent impulses into quite a group of subdivisions. Now, what differentiates a sensory neuron of the tactile system from one of the pain system? There is nothing specific *per se* in this neuron. Regarding conscious sensory impressions, it may be said that the only *sine qua non* is the sensory center for that particular sensation in the brain. To be sure it is found that the nerve fibers leading to this center are grouped more or less together in systems, but the fibers themselves possess no more specificity

than do telegraph wires to two different receiving stations. How is it, then, that stimulation over a given square centimeter of cutaneous surface, first with a warm metal plate, then with a piece of cotton wool, then by a pin prick, will give three altogether different sensory impressions? To understand this one must realize that to this square centimeter of skin in question there are distributed a number of nerve fibers, peripheral axons from cells located in the posterior root ganglia of the spinal cord. Though these axons may claim no specificity of function, yet they are connected in the skin with end-organs, the thresholds of stimulation of which are quite specific. In regard to pain sense it should be stated that in all probability there is no end-organ in the sense of a tactile end-organ; the fibers for superficial pain end in the long fine naked fibrils among the epithelial cells, but each fiber shows a bulbous swelling at the end as demonstrated by Cajal with methylene blue preparations. There may be, let us say, fifty end-organs in this area specific to thermal stimuli, fifty specific to pain stimuli and fifty specific to tactile stimuli. As a matter of fact, the relative number of the several varieties of end-organs is far from constant. A certain area may have end-organs specific to heat and none responsive to cold stimuli; likewise, an area may have tactile end-organs and none for temperature and *vice versa*. An end-organ is specific to a certain form of stimulation when the threshold value for that stimulus is lower in that end-organ than for any other form of stimulation. This concept does not preclude the possibility of an end-organ reacting to another form of stimulus, but it fixes the minimal point at which it reacts to a specific form and any other form of stimulus, in order to evoke a response, must be of much greater magnitude. Even with increased stimuli it is likely that certain end-organs do not react with a given stimulus not specific for it. Starling holds, for instance, that stimulation of a tactile end-organ does not give a pain sensation. This may be true. On the other hand, in the experiments of Head and Rivers it would seem that excessive thermal stimuli might provoke pain sense. In one of such experiments they record, "it was impossible to say whether the pain was accompanied by any thermal quality." This condition of affairs in phylogeny and ontogeny can lead only to one end and that is the education or the specialization of certain pathways to conduct certain kinds of messages.

Using again the telegraph as a simile, we must take into account not only the wire but the sending and the receiving station. What would happen could we take the fifty fibers attached to the thermal end-organs, divide them a few centimeters from their end-organs, and join the distal stumps to the central ends of the fifty fibers, previously cut, which lead to the tactile end-organs? In order to understand this question let us suppose that the threshold of stimulation for each of these types is ten units and that in order to stimulate one of them with a stimulus other than its specific form

will take eighteen units. If a tactile stimulus of ten units now be applied to the surface in question no sensation will be perceived; but should a tactile stimulus of eighteen units be used, a sensation will be recorded in the brain not thermal in type corresponding to the end-organs, but tactile corresponding to the specific cells of perception in the brain. But a thermal stimulus of ten units will also give a tactile impression. Again, should an experimental anastomosis be made between the cervical sympathetic and the lingual nerve, then stimulation of the sympathetic would cause a nerve impulse which would be continued from the sympathetic nerve, but instead of a sympathetic phenomenon (vasoconstriction in the head and neck) we would have vasodilatation in the tongue and secretion of saliva.

From these experiments, the first purely hypothetical, the second practical, we learn that reception specificity depends on the end-organ and perception specificity on the reception center in the brain.

In this connection it were well to consider the question of specificity of peripheral afferent fibers for purely reflex acts. Howell (8) has stated: "A sensory fiber carrying an impulse which eventually reaches the cortex of the cerebrum and gives rise to a conscious sensation may, by means of its collaterals, connect with motor nuclei in the cord or medulla and thus at the same time give origin to involuntary and even unconscious reflexes." This is a most unlikely condition, as it is well known that the posterior root fibers, which pass directly forward in the gray matter to make connection with the cells of the anterior horn, receive their myeline sheaths at a much earlier period than do those long fibers of the posterior column. Therefore, it is likely that the two systems are morphologically as well as functionally separate.

AFFERENT NEURONS

Grouping of Afferent Neurons in Peripheral Nervous System

We have considered four varieties of conscious sensory impression: tactile, heat, cold and pain. In order to group afferent impulses we may well discuss briefly the other conscious and unconscious types.

If an electrode from a faradic coil be placed over a touch spot and the current gradually increased from zero, at a certain point in intensity of current the electric sensation is perceived. Some consider this as a separate variety with specific end-organs, while others think that it is simply the electric stimulation of tactile variety. Although one cannot speak with surety, it is probable that the latter is the correct interpretation. When the electric stimulation reaches a certain point in intensity, pain is recorded. This may be explained by the radiation of current to contiguous

pain fibers and not to a hyperstimulation of tactile end-organs. The work of Head seems to me quite conclusive in this regard; he found in a given cutaneous area to which the sensory nerve had been sectioned that, while there was still analgesia, there was preservation of superficial electric sense which did not change to pain on the great increase of current. Whether the electric and tactile senses be identical, there can be no doubt as to their intimate association. It is also likely that the ability to localize correctly a sensory stimulus and to discriminate between one and two simultaneous stimuli, as by the Weber compass, is dependent on the tactile sense.

The forms of sensation considered above are those produced by stimulation of the surface of the body. There is another important group, the deep sensations, which includes deep pain sense, pressure sense, sense of position and osseous sense. The *deep pain sense* is demonstrated by pressure over muscles, bones or organs and is independent of superficial pain sense. The *sense of pressure* is tested by having the patient differentiate between the pressure downward of two different weights. A more accurate and satisfactory method is the use of the baresthesiometer; but clinically this sense is usually tested by the different pressures from the finger of the examiner. Weber has studied this sense and has found that in order for a patient to discriminate between two pressures, the increment must be 1/30 of the pressure previously applied, that is to say, normally discrimination between 30 and 31 pounds will be possible and minimal, but the patient could not differentiate between 30 and 30.5 pounds. This is known as Weber's law. The *sense of position* is both conscious and unconscious and is at once the most complex and important type. Sensory end-organs in the muscles, tendons and joints convey afferent impulses which record consciously the amplitude of motion in a joint and the amount of work performed by the groups of muscles, while unconscious impulses of joint position and muscle tonus are recorded in the vermis of the cerebellum. In passive movement of a limb we obliterate as much as possible, though probably not entirely, the conscious sensory stimuli from the muscles, and the patient relies chiefly on the conscious joint impulses to tell in what position the part has been placed, and on the conscious and unconscious impulses to reproduce this attitude in the other limb. Finally, we note the conscious and unconscious impulses evoked by the use of a deep-toned tuning-fork placed over a bony prominence. This is frequently spoken of as the *osseous sense,* or the sense of vibration.

The work of Head and his collaborators has done more to bring order out of chaos in this question of peripheral sensory grouping than any other contribution in many years. Based largely on his work I would give the following scheme of afferent impulses:

The epicritic and protopathic varieties are transmitted through the

Epicritic sensation	Tactile (Electric and localizing)		Conscious
Temperature between 26° and 37° C.			
Protopathic sensation	Heat		
Temperature below 26° or above 37° C.	Cold		
	Pain		
Deep sensation	Pressure	Active [1]	Conscious and Unconscious
	Position	Passive [1]	
	Osseous		

[1] The terms active and passive are here used to indicate sense of patient to passive movement and to active movement.

cutaneous sensory nerves; deep sensibility by means of their muscular and deep branches.

Some physiologists reckon stereognosis as an elementary sense. This seems to me quite untenable. It should be termed stereognostic perception, as it is not elementary in the sense of tactile impression, but is made up of a complex of elementary sensations best shown by the following scheme:

Stereognostic perception	Spatial relation	Position, Joint, Conscious		Deep sensation
	Weight	Position, Muscle, Conscious		
	Quality of Surface	Pressure		
		Tactile	Epicritic sensation	
	Temperature	Heat	Epicritic and protopathic sensation	
		Cold		

Grouping of Afferent Neurons in Spinal Cord

A knowledge of the rearrangement and further course of the afferent peripheral neurons within the spinal cord, as well as a clear understanding of their connections with afferent neurons of the second order, involves a spatial conception which is as difficult as it is necessary to accurate localization of a spinal cord lesion. Most if not all of the proximal axons of the posterior ganglion cells, after entering the posterior column, divide into a long or ascending and a short or descending branch. Numerous collaterals, springing at right angles from the branches, serve to bring several spinal segments into association in reflex mechanism.

The afferent neurons, which in the peripheral nervous system have been arranged, as stated, in deep and superficial nerves, undergo a complete change in their relations as soon as they enter the spinal cord. As our chief interest at the present time is the physiological point of view as it bears upon spinal localization, it seems well first to follow function rather than delimit anatomical boundaries of tracts.

The Tactile Impulse.—There is no question which has been the subject of more disagreement than the spinal cord pathway of tactile sensation.

Shortly after Brown-Séquard published his thesis on the centripetal systems, in 1846, there began to appear many clinical reports of hemisection of the spinal cord mostly characterized by crude observation and premature deduction. The subject soon became so chaotic that it is safe to say that, given a hemisection of the cord in the midthoracic region, any incongruous sensory syndrome could be defended by cases quoted as precedent. Therefore, physiologists and clinicians from time to time advanced their theories as to sensory decussations, homo- and heterolateral transmissions; and any opinion was sure to meet both argument and repudiation.

In 1910 I reported (1) a study of disturbance of sensation in syringomyelia, in which I explained the preservation of tactile sensibility in cases of destruction of the posterior columns on the hypothesis of Ludwig Mann (10). Although I now believe that tactile stimuli can be transmitted in the anterolateral tract of the opposite side, yet the work of Head and Rivers and of Starling make Mann's physiological explanation of summation of stimuli in pain and the simple passage of the tactile stimulus without summation over the same route (". . . *die tactilen Reize . . . einfach passiren, ohne zu summationserscheinungen zu führen*") quite untenable.

The principal tract for tactile sensation is in the posterior column of the same side, and passing up this column the tactile stimuli reach the nucleus gracilis and the nucleus cuneatus where they are transferred to sensory neurons of the second order, forming the internal arcuate fibers and the medial lemniscus. It is in the internal arcuate fibers that the decussation takes place and the tactile sensory impulses are transferred to the opposite side of the cerebrospinal axis. Undoubtedly it is possible for tactile impression under certain conditions to pass to cells of secondary sensory neurons in the gray matter midway between the anterior and posterior horn, from whence they pass via the anterior white commissure to the anterolateral tract of the opposite side in close relation to the fibers for temperature. One of two explanations can account for this: Either some of the axons leading from tactile end-organs take this latter route, thereby giving us a specific tactile route in the anterolateral columns; or else, by the near relationship between the sense of touch and the epicritic temperature sense, the pathway of the latter is easily educated, when the natural pathway to tactile sensation is destroyed, to carry tactile impressions interpreted as such in the perceptive centers in the brain. In this latter theory the anterolateral tract would be facultative to tactile impressions. Reëducation in the central nervous system is too well recognized to need a defending brief. Whatever the physiological explanation be, the dominant pathway for tactile stimuli lies in the posterior columns.

Déjerine teaches that tactile stimuli enter the cord by the medium length posterior fibers (*fibres radiculaires moyennes*) and, although they pass up the posterior column of the same side for possibly a number of segments, eventually they are transferred to cells of the second order,

lying in the intermediate gray tract, whose axons cross in the anterior commissure and continue upward by way of the anterior part of the anterolateral tract. Should this be true, a severe destructive lesion of the posterior columns high up in the cervical region should leave tactile sensation at least for the lower limbs and lower part of the trunk unimpaired, a condition which, of course, does not obtain.

Pain and Temperature Impulses.—Stimuli of pain and temperature pass into the posterior horn soon after entering the spinal cord, most likely reaching the gray matter in the same segment in which they entered. In the intermediate gray matter of the same side, these impulses are transferred to cells of the second order whose axons cross in the anterior white commissure and then continue upward in the anterolateral tract. Déjerine would confine these fibers to the posterior part of the anterolateral tract. But a case reported by Spiller (16), in which small discrete tuberculomata occupied positions on each side of the spinal cord, involving the anterolateral tracts, makes one rather dubious about receiving Déjerine's *ex cathedra* statement. In Spiller's case certainly more of the tactile fibers, according to Déjerine's concept, than those for pain and temperature would have been involved. However, in this case there was chiefly loss of pain and temperature sense and practically no involvement of tactile sensation. Déjerine (6) also states that the decussation of these fibers takes place in the gray commissure. In lesions of the intermediate gray matter I have found by the Marchi method well-marked degeneration in the anterior white commissure, but none in fibres crossing in the gray commissure, if there be such. I am inclined to doubt the existence of any well-defined decussation in the gray matter anterior to the central canal.

Pressure Sense.—In considering the sense of pressure I have relegated it wholly to deep sensation. It seems to me extremely doubtful whether there be an epicritic tactile pressure sense as Déjerine (6) suggested, *"Les impressions tactiles superficialles—attouchement léger—et les impressions de pression tactile."* The stimuli of pressure pass up the posterior columns of the same side and, like those of tactile sensation, are in all probability transferred to the neurons of the second order in the nuclei of Goll and Burdach; these neurons conduct them via the middle lemniscus to the thalamus of the opposite side, as in the case of tactile impressions.

Sense of Position.—In discussing the afferent impulses concerned in the sense of position, we deal with conscious and unconscious impulses both belonging to the deep sensory group but having a very different course in the spinal cord and a different termination in the brain. As indicated in the scheme of afferent impulses, the conscious perception of position of a limb in active (automatic) movement is due to afferent impulses from the joints giving the angle through which the limb has moved with the joint as a pivot, also to impulses from the muscle groups engaged in the movement recording the amount of work done. When the

limb is passively moved by the examiner, the chief source of supply of afferent impulses is the joint, as the muscles do not contract. To be sure, there may be some afferent impulses from the passive movement of already lax muscles or the physiological antagonists of the muscle group, for the particular movement may give afferent impulses due to a slight increase in tension; but the chief source of impulses in the passive movement is the joint. These conscious impressions pass up the posterior columns of the same side and their further course is, in all probability, the same as that for tactile and pressure sense.

The unconscious impulses which play such an important rôle in the maintenance of equilibrium and the synergic action of groups of muscles have been the subject of much study and speculation. Unfortunately at the present day as in the past, clinicians and physiologists have been perfectly willing to accept certain stereotyped statements as facts, albeit careful research often fails to determine sufficient evidence to support them. There are two points which may safely be assumed as beyond criticism: first, the cerebellum receives unconscious stimuli and neither receives as an end station nor transmits to the cerebrum stimuli of conscious sensory nature; secondly, the direct cerebellar tract and that part of the anterolateral ascending tract known as Gowers' tract convey impulses to the cerebellum. We are on safe ground when we accept these two statements as premises. A few fibers passing up the posterior columns arborize about a small collection of cells which lies in the outermost portion of the nucleus of Burdach, called by some von Monakow's nucleus. The axons of these cells enter the restiform body of the same side and are accepted by Déjerine as homologous to the direct cerebellar tract.

Efforts have been made to assign to each of these tracts certain parts of the body, but so much diversity of opinion exists that it is impossible to consider the question settled. Gowers' tract makes its appearance in the third lumbar segment, the direct cerebellar tract in the twelfth thoracic or first lumbar. These levels are not absolutely constant, but it can be said that the direct cerebellar tract appears at a higher level than that of Gowers'. Now, it is taught by Déjerine that Gowers' tract transmits deep, unconscious impressions from the trunk, neck and upper extremities, and that the direct cerebellar tract carries impulses of like nature from the trunk and lower limbs. At once we are confronted with an apparent incongruity. If the direct cerebellar tract transmits the stimuli from the lower limbs, it is strange that the appearance in the lateral columns should be at a higher level than that of Gowers' column, which is supposed to represent the upper limbs. The column of Clarke from which come the axons for the direct cerebellar tract is found as low as the first lumbar segment. It is impossible to say how low down in the cord are located the cells giving origin to Gowers' tract, as they are not sharply delimited as in the case of Clarke's column.

It may be that though the fibers in the lowermost segments occupy the position topographically of Gowers' tract yet they are in reality short association fibers, binding a low segment of the cord with one higher up and are not physiologically to be considered as Gowers' tract. A stronger argument for the specificity of these tracts, as indicated by Déjerine, is that the direct cerebellar tract receives but few fibers from the segments of the cord giving origin to the roots of the brachial plexus; and it is chiefly in lesions of high level that we are easily able to trace Gowers' tract up into the pons. I see no reason for believing that any of the fibers of the direct cerebellar tract come from the contralateral gray matter or that any fibers of Gowers' tract take origin on the same side of the cord. In an historical résumé, MacNalty and Horsley (9) show how conflicting are the views on this question.

There is a growing opinion that fibers of the direct cerebellar tract end in the superior vermis and that those of Gowers' tract end in the inferior vermis. Déjerine states this categorically and gives very definite anatomical diagrams of the medulla, pons and cerebellum illustrating his views. Elliot Smith (5) says: "Bruce has shown that the fibers of the spinocerebellar tract (speaking of the direct cerebellar part) ultimately lie in the center of the restiform body, forming as it were its central core, and that, in the cerebellum, they can be traced to the superior vermis."

Concerning Gowers' tract, Schäfer and Symington (14) say: "It enters the cerebellum over the superior peduncle and in the superior medullary velum. Its fibers end mainly in the lower part of the worm, many crossing the middle line." Further on they say: "The fibers from Gowers' bundle are distributed mainly to the caudal half of the vermis on both sides." Piersol (13) concurs in this. MacNalty and Horsley (9) take issue with this statement, claiming: "From the point of view of afferent function, therefore, there cannot be said to exist any evidence of differentiation of the cerebellar cortex into localized receiving stations for the impressions (muscular, arthric, etc.), which ascend from the arm, trunk or leg muscles, joints, etc., respectively."

In the face of these opinions, especially those of Déjerine, Elliot Smith, Bruce, Schäfer and Symington, any attempt at cerebellar localization in which the upper extremities are relegated to the superior surface and the lower to the inferior (Mills and Weisenburg, 11), must be supported by more trenchant facts than any to which I have had access.

REFLEXES—THEIR MECHANISM, INHIBITION AND LOCALIZATION

When an afferent impulse provokes a motor or secretory response independent of any conscious or volitional mechanism, we speak of the phe

nomenon as a reflex act. A reflex act postulates an afferent pathway, an efferent pathway and the synapse between the two, as well as the afferent end-organ of stimulation and the particular efferent ending, neuromuscular or neuroglandular junction. We speak of this mechanism collectively as the reflex arc, and any reflex activity depends on the integrity of this reflex arc. The spinal cord, with its thirty-one segments, presents a great collection of reflex arcs superimposed one on top of the other; the posterior roots carry the afferent limbs of these arcs, the anterior roots the efferent, while within the gray matter are located the synapses.

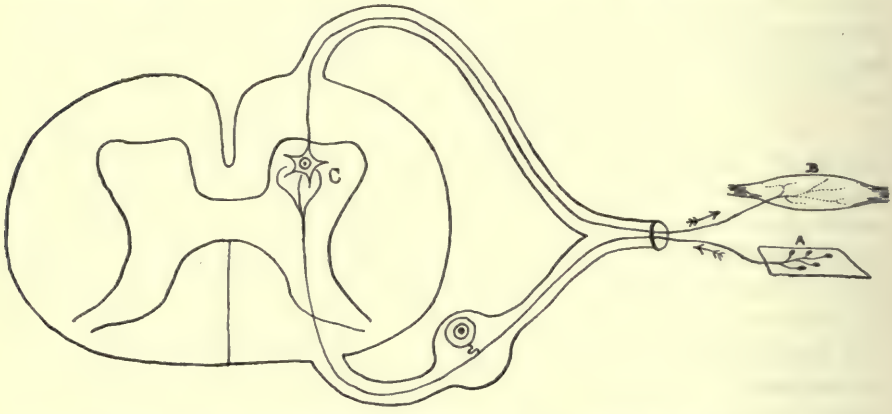


FIG. 79.—DIAGRAM OF MECHANISM OF A REFLEX ACT.

A, Afferent (sensory) impulse from end-organ in skin or tendon; B, efferent (motor) impulse to muscle; C, synapse in the gray matter of spinal cord between the two limbs of the reflex.

In the diagram (Fig. 79) *A* represents a cutaneous surface with its afferent or sensory nerve, the afferent limb of the reflex arc; *B* represents a muscle whose function it is to remove *A* from the proximity of a nocuous stimulus, and to it is attached the motor nerve fiber, the efferent limb of the arc. At *C*, in the gray matter of the spinal cord, is the synapse between these two limbs. A stimulus at *A*, such as a pin prick, or a thermal or electrical stimulus, will cause an impulse to run to the spinal cord, where it is transferred across the synapse to the efferent limb along which it travels to the muscle causing a contraction and the removal of the part (*A*) from the stimulus or irritation. This, of course, is a most simple and diagrammatic illustration and demonstrates two points: first, the mechanism; second, the motive, which in this case is defense. When we trace the reflex activity of the human body back in the animal kingdom, it becomes more than likely that what is present in man as a complicated mechanism with more or less utilitarian ends leads back through a great phylogeny to the one motive, *defense*.

The rate of transmission of the impulse in the afferent and efferent

limb is about 120 meters per second, but the transference in the gray matter of the spinal cord from the afferent to the efferent limb, that is, through the synapse, is quite variable, in certain cases like the knee jerk being 0.002 of a second, in other reflexes much longer.

Distribution of Posterior Root Nerve Fiber.—Attention must be called to the peculiar collateral distribution of the posterior root nerve

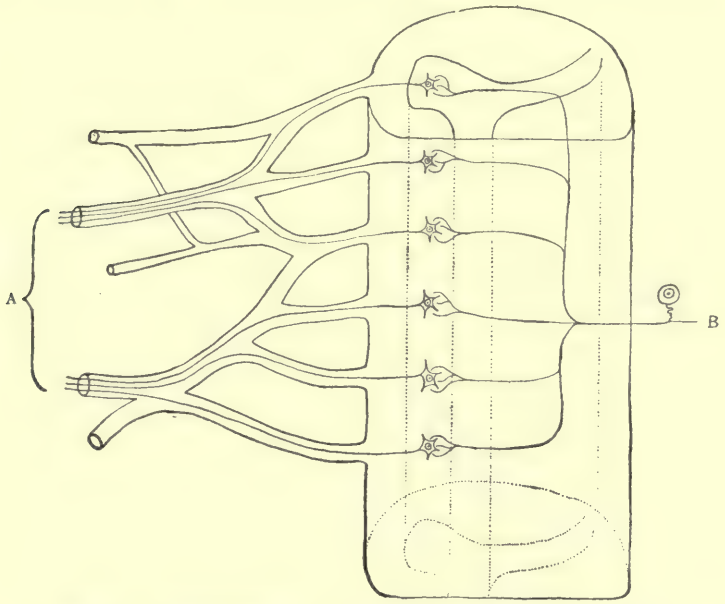


FIG. 80.—DISTRIBUTION OF A POSTERIOR ROOT NERVE FIBER.

A, Physiological arrangement of efferent fibers to functional group of muscles; B, stimulation of this posterior fiber will not send a motor discharge through the whole plexus, but only through the nerves as indicated, producing an orderly action of a group of related muscles.

fiber for reflex action. As shown in the diagram (Fig. 80), afferent impulses from one posterior nerve root are distributed to a much greater field of activity than one anterior nerve root. The reason for this is that no muscle receives its motor supply from one anterior nerve root, and no anterior nerve root gives its entire motor content to one muscle. The arrangement of muscles in groups for functional ends, such as extension, flexion and adduction, makes it necessary that the efferent impulses shall likewise be allotted so that a physiological group of muscles shall act as a unit through the medium of a given set of afferent stimuli. To this end the peripheral nerve supply, especially in the four limbs, loses its segmental character and is formed into plexuses in which the rearrangement makes for the synergic action of functionally correlated muscles.

Inhibition of Reflex Activity.—Reflex activity is normally subject to

inhibition, which is of two types: first, an automatic depressor effect of an antagonist reflex arc in action; second, the reflex inhibitory mechanism, which has its origin most likely in the brain (cerebrum or cerebellum) and passes down the spinal cord exercising a control on all spinal reflex arcs. There is reason to believe that the fibers for reflex inhibition are closely associated with the crossed pyramidal tract. The first type of reflex inhibition, which has been so carefully studied by Sherrington, may be exhibited by the inability to produce in the spinal dog the scratch reflex while the flexor reflex is in action. As we shall see later on, reflex activity is closely associated with muscle tone, and this first type of reflex inhibition may be demonstrated by the experiment which shows that the tone of the ham-string group of muscles is lowered while the knee jerk is in operation. Of the second type of inhibition not much can be said. One postulates a reflex inhibitory center and pathway, because lesions above the reflex arc allow the reflex activity to run riot, a fact well demonstrated in most upper motor neuron diseases. There has been much speculation as to where this reflex inhibitory center lies. Some have placed it in the cerebrum and others in the cerebellum or medulla. It is a well-known fact that the cerebellum exercises a great power over the deep tendon reflexes, but this is chiefly exhibited by the fact that in cases of disease of the lateral lobe of the cerebellum there is diminution or loss of tendon reflex activity on the same side of the body. The most likely pathway for this nervous mechanism is as follows: Cortex of lateral lobe of cerebullum, dentate nucleus, superior cerebellar peduncles, red nucleus of opposite side, rubrospinal (von Monakow's) tract to original side and down lateral column of cord just central to the crossed pyramidal tract. Now the anterior limb of the internal capsule carries the frontothalamic band to the red nucleus of the same side, and although a rubrocerebellar tract has not been demonstrated it is possible that the action of the cerebral hemisphere anterior to the fissure of Rolando may be a determining factor in the action of the lateral lobe of the cerebellum on the opposite side in maintaining tone. This might account for the hypertonus and increased reflexes on the paralyzed side in hemiplegia, or brain tumor, the prefrontal region being influenced by the proximity of the lesion. It is a well-known fact that frequently we find at autopsy the cerebral hemisphere of one side and the lateral lobe of the cerebellum of the opposite side atrophic. When we come to the question of the final explanation of the mechanism of inhibition we are as yet in the dark. Howell's work on the pneumogastric inhibition of the heart is the most suggestive. He reduces the question to a chemical action.

But up to the present time all other concepts of inhibition seem to deal in negative quantities. From now on when we refer to reflex inhibition we shall use the term in its clinical sense, which indicates a nervous mechanism from above.

Changes in Reflex Activity.—Reflex activity may be increased or decreased by endogenous substances circulating in the blood. This is seen in various toxic conditions. As might be expected, at times a circulating toxin will first increase reflex activity and then decrease it. The part of the reflex arc which most likely plays the greatest rôle in these alterations in activity, be they increase or exhaustion, is the synapse. Some drugs cause an increase in reflex activity, most likely by lessening the synapse resistance, as well as acting as irritants to the afferent or efferent limb; strychnin may be instanced as a good example. Other drugs depress the activity; of these, physostigmin, coniin and the bromids may be mentioned. Other drugs increase reflex activity chiefly by lessening the reflex inhibitory action; atropin is supposed to be of this class.

Muscle Tone.—Right here it were well to mention muscle tone, a phenomenon closely associated with the reflex arc. If a decerebrate frog with spinal cord and spinal nerves intact be hung upon a support, it will be noticed that the hind legs are not hanging limply, but are very slightly flexed at the hip and knee joints. In other words, there is a condition of tonus in the muscular system. Let us now cut the posterior nerve-roots to the right hind leg; at once it hangs flaccidly. Cutting the anterior nerve-roots on the opposite side causes the same phenomenon in the left leg. In other words, tonus in the lower animals is dependent upon the reflex arc. In the higher primates the reflex arc factor is associated with a cerebellar influence which tends to stimulate tonus. How necessary this cerebellar mechanism is, it is hard to estimate. Probably it differs in importance in different individuals. The total loss of all deep reflexes in cases of section of the upper cervical cord has been ascribed by some to a loss of the tone-stimulating action of the cerebellum. Unfortunately for this argument, cases occur in which the lesion is complete and the reflex activity not lost. It may be that the individual reverts phylogenetically to a type in which reflex mechanism is more independent of cerebellar control than in man. One symptom of disease of a lateral lobe of the cerebellum is a condition of hypotonus on the same side.

Classification of Reflexes.—We divide reflexes into deep, superficial and sympathetic. The deep variety are further subdivided by some authorities into tendon and periosteal reflexes.

Tendon Reflexes.—The history of the tendon reflex is interesting chiefly on account of the fact that for many years a great difference of opinion obtained as to the true reflex character of the knee jerk. Many held that the length of time between the stimulation (striking the patellar tendon) and the reaction was too short to allow an impulse to travel up to the spinal cord and back again to the muscle; while others defended the reflex nature of this phenomenon. In 1900, Sherrington classified the knee jerk among the pseudoreflexes, thereby lending additional weight to the former school. But finally careful measurements of the time of the

several parts of the reflex arc by means of the string galvanometer enabled Snyder (15) to prove definitely the knee jerk a true reflex with a very short synapse time (0.0022 of a second). This opinion has now been accepted generally.

Cutaneous Reflexes.—The cutaneous reflexes have likewise claimed discussion. Sherrington found on the removal of the motor cortex in the monkey that, although after a time the tendon reflexes would return, the cutaneous reflexes would not. From this it was argued that the mechanism of the cutaneous reflex was not confined to the spinal cord, but was dependent on the higher centers in the brain. So far as the human being is concerned, this has been proven incorrect. Déjerine has found preservation of cutaneous reflexes in the human being, even when there has been a complete lesion of the spinal cord.

Sympathetic Reflexes.—Of the sympathetic reflexes I shall mention in passing only the pupillary light reaction.

Deep Reflexes

Response of Deep Reflexes.—Deep reflexes are provoked by stimulation of nerves of deep sensation. When the tendon is struck afferent impulses from sensory end-organs in the tendon pass to the spinal cord by way of the nerves of deep sensation. It is also readily understood that the act of striking the tendon in question subjects the muscle to a sudden minute increase in tension, thereby stimulating sensory nerve endings in the muscle substance. That this is so, is demonstrated by the fact that the knee jerk can be elicited after the sensory nerves to the patellar tendon have been cut. A periosteal reflex depends on stimulation of end-organs in the periosteum and is evoked by a blow from a percussion hammer over a bony prominence.

When we find a reflex present and normal we learn two things: first, there is no lesion of the segments through which the arc passes great enough to impair its integrity; second, it is reasonable to conclude that there is no upper motor neuron involvement of moment. The loss of a reflex in any condition except cerebellar disease or complete transverse lesion of the spinal cord, betokens involvement either of the segments concerned in the reflex or of the limbs, afferent or efferent, of the arc. The presence of the reflex in an exaggerated degree, aside from a functional exaggeration, indicates involvement of the reflex inhibitory mechanism, which, as we have seen, may be anywhere between the motor cortex and the lateral columns of the cord.

Classification.—The following deep reflexes are those most frequently studied clinically:

DEEP REFLEXES

Reflex	*Segments concerned in arc*
Biceps	Cervical V, VI.
Triceps	Cervical VI, VII, VIII.
Scapulohumeral	Cervical VII, VIII; Thoracic I.
Patellar (Knee jerk)	Lumbar II, III, IV.
Achilles	Lumbar V, Sacral I, II.

BICEPS REFLEX.—To obtain the biceps reflex, the patient's arm is supported, the elbow resting on the examiner's left hand, and the back of the forearm and hand passively supinated and resting on the left forearm of the examiner. The patient's elbow should be flexed at an angle of about 135 degrees. Placing his left thumb over the biceps tendon, the examiner strikes it with his hammer and there follow a flexion and slight pronation of patient's forearm.

TRICEPS REFLEX.—The triceps reflex may be obtained by allowing the forearm to hang down, the arm being elevated to a plane parallel with the floor. The triceps tendon is then struck just proximal to its insertion in the olecranon and an extension of the forearm on the arm is the result.

SCAPULOHUMERAL REFLEX.—This is best obtained by having the patient stand and lean slightly forward; the inner edge of the scapula is then struck about two inches from the inferior angle. The reflex consists in an adduction of the arm and, in many cases, a slight supination of the forearm, which can be seen by observing the patient's thumb.

PATELLAR REFLEX.—The usual method of eliciting the knee jerk is by striking the patellar tendon when the knees are crossed. A more delicate method is to have the patient sit with feet parallel and on the ground, knees flexed at an angle of about 120 degrees. The patient is then instructed to keep both the heels and the toes on the ground, but to exert pressure particularly with the balls of the feet. The patellar tendon is then struck. This method, by reason of the effort made to press down the toes, seems to be self-reënforcing, and often when the usual method fails to elicit a response, this method succeeds. Where the reflex is small the anterior aspect of the thigh should be exposed and both watched and palpated in order to detect the slightest quadriceps action.

ACHILLES REFLEX.—To demonstrate the Achilles tendon jerk, have the patient kneel on the seat of a chair, knees all the way back, so that the feet hang over the front edge of chair. The shoes being removed, strike the tendo achillis near its insertion into the calcaneus.

In cases of upper motor neuron disease where the reflex inhibitory mechanism is destroyed or impaired the phenomenon of ankle clonus may often be elicited. To demonstrate this, have the knee supported, slightly flexed (about 150 degrees), and, grasping the ball of the foot, suddenly flex the foot on the ankle. A series of rhythmic contractions of the gastroc-

nemius, about four per second, is thus easily demonstrated. When the damage to the upper motor neuron is severe, this clonus is persistent, but where the involvement is incipient, it is easily fatigued, the examiner's hand feeling possibly only two or three abortive kicks.

The above are the deep reflexes which are easily elicited. There are others which are not constant even in health and which throw light on no segments not covered above and some of which, moreover, are hard to demonstrate; therefore I would refer anyone particularly interested in the subject to any of the larger works on neurology.

Method of Jendrassik.—In case it be desired to reënforce reflex activity, as frequently happens when we are not sure whether we have any response after striking the patellar tendon, this may be done by the method of Jendrassik, which consists of locking the fingers of the hands together and at a signal straining to pull them apart; the blow of the hammer should fall on the tendon synchronously with this muscular strain.

In many persons, normal and abnormal, the tendon reflexes are frequently quite small, particularly in a warm environment. In these cases a cold shower or even stripping the subject and taking him into a cold room often greatly reënforces all reflex activity.

Often the extent of reflex response will be proportionate to the amount of stimulation. To be more concrete, the minimal stimulation for a certain reflex activity may be transmitted in the spinal cord to the nerve cells governing one group of muscles and with this minimal stimulus this group and this alone will react. Any increase in the stimulus will not only provoke a greater response in this group, but will cause afferent impulses possibly to pass *via* collaterals to segments above or below the main reflex segment and thus bring into play other efferent neurons and so, as it were, expand the reflex activity. An analogous condition to this mechanism of extension of the reflex arc may account for the phenomenon of what Babinski termed "inversion of the reflex." In this, one notes a reflex response different from what should normally obtain from the given stimulus. An explanation of this paradox is that the reflex arc for the chief muscle groups is impaired or broken and that there takes place an "irradiation" of stimulus to a neighboring center thereby producing the inverted response. Inverted responses have been noted in the radial, triceps, Achilles, and patellar tendon reflexes.

Cutaneous Reflexes

Classification.—The chief cutaneous reflexes which are studied are as follows:

CUTANEOUS REFLEXES

Reflex		*Segments concerned in arc*
Abdominal	Epigastric	Thoracic VI, VII.
	Midabdominal	Thoracic VIII, IX.
	Inferior abdominal	Thoracic X, XI, XII.
Cremasteric		Lumbar I, II.
Gluteal		Lumbar IV, V, Sacral I.
Plantar		Lumbar V, Sacral I, II.
Bulbocavernous		Sacral III, IV.
Anal		Sacral V, Coccygeal I.

By careful examination of these reflexes one may account for every segment in the cord, except the first, second, third and fourth cervical and the second, third, fourth and fifth thoracic.

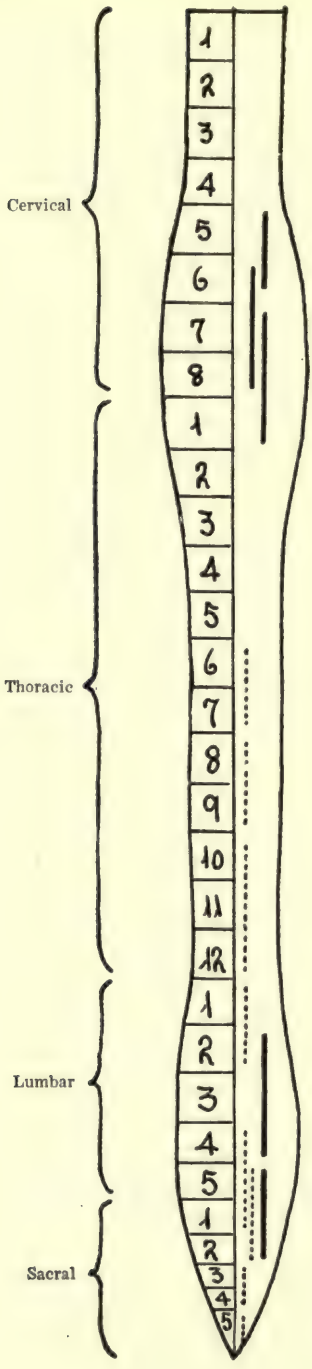
ABDOMINAL REFLEX.—The abdominal reflex is a contraction of the rectus abdominalis on one side caused by cutaneous irritation of the same side. It may be divided into three separate reflexes: The epigastric, which is a contraction of the upper third of the muscle on irritation of the overlying skin and is dependent on the integrity of the sixth and seventh thoracic segments; the midabdominal, which is provoked by stimulation of the skin on a level with the umbilicus, the segments involved being the eighth and ninth thoracic; and the inferior abdominal, which is elicited by stimulation of the skin over the lower third of the rectus, the segments being the tenth, eleventh and twelfth thoracic. The abdominal reflex often fails in old subjects with fat and pendulous abdomens.

CREMASTERIC REFLEX.—The cremasteric reflex is the drawing up of the testicle on irritation of the skin on the inner and upper surface of the thigh. It is often absent in the aged, but when present depends on the first and second lumbar segments.

GLUTEAL REFLEX.—The gluteal reflex is the contraction of the gluteus maximus on stroking or pin prick over the buttock. Its reflex arc passes through the fourth and fifth lumbar and first sacral segments.

PLANTAR REFLEX.—One of the most important reflexes, because most constant, is the plantar. On stimulation of the sole of the foot there is normally a plantar flexion of all five toes. This reflex depends on the integrity of the fifth lumbar and first and second sacral segments. In lesions involving the upper motor neuron system plantar irritation produces a slow extension of the great toe with either plantar flexion or extension of the other toes. The great toe is the index in this case and the reaction is known as the Babinski reflex.

Babinski Phenomenon.—This most valuable sign should always be sought in possible upper motor neuron difficulty. I have reported a case of concussion of the brain with temporary complete blindness (2) which for several hours showed spasticity and a well marked Babinski reflex.



Within twenty-four hours the blindness, spasticity and Babinski reflex had disappeared. This case demonstrates how, even in a fleeting condition, where the upper motor neuron system is involved you may get the Babinski reflex. Marie considers the Babinski phenomenon an example of a defense reflex and despite the assertion of Déjerine to the contrary he is undoubtedly correct.

Oppenheim Phenomenon.—Oppenheim described a great toe phenomenon which bears his name. In this, the Oppenheim reflex, the stimulus is a quick, rough and deeply pressed stroke of an object like the handle of a percussion hammer from above downward on the inner aspect of the tibia. The result in a normal individual is either nothing or else a slight plantar flexion of the four lesser toes. In case there be upper motor neuron lesion, the result is a reaction in the toe similar to the Babinski reflex. The Oppenheim reflex is really nothing more than the Babinski reflex with the stimulation applied more roughly and at a different place. Bregman says that he has seen it appear before the Babinski reflex but that may be explained by the fact that the Babinski reaction is never tested with such an intense stimulus.

Bulbocavernous Reflex.—The bulbocavernous reflex is exhibited by palpation of the perineum midway between the scrotum and anus while the dorsum of the glans penis is pricked with a pin. Under these conditions a contraction of the bulbocavernous muscle is felt. The reflex arc

Fig. 81.—Diagram of Segmental Distribution of Reflex Arcs.

The cutaneous reflexes are indicated by the dotted lines, the tendon reflexes by the heavy lines. (See tables, pages 113 and 115.)

for this phenomenon lies in the third and fourth sacral segments.

Anal Reflex.—The anal reflex is tested by placing the patient in the knee-chest position and then pricking the region about the anus with a pin. A contraction and retraction of the anus is the result and this depends on the integrity of the fifth sacral and the coccygeal segment.

EFFERENT NEURONS

Efferent Neuron Systems.—The efferent systems may be divided into the upper and lower motor neuron systems. As it is necessary physiologically to consider the sensory or afferent systems from the periphery upward so it is necessary to consider the efferent systems from above downward and to the periphery.

Anatomically we may divide the fiber tracts, motor and sensory, in the spinal cord into the endogenous and exogenous. The endogenous nerve fiber has its cell of origin within the spinal cord and may be either centripetal (cells of Clarke's vesicular column) or centrifugal (anterior cornual cells). Likewise the exogenous nerve fiber whose cell body lies without the spinal cord may be either centripetal (cells of the posterior root ganglia) or centrifugal (fibers from motor cells of motor cortex). The short descending tracts in the posterior columns formed by the descending branches of the proximal axons of posterior ganglion cells (cornual tract of Schultze, oval field of Flechsig, etc.) are reckoned among the afferent neuron systems.

The following efferent tracts will now engage our attention: The crossed pyramidal (or lateral pyramidal), the direct pyramidal, the direct ventrolateral pyramidal (Spiller's tract), the rubrospinal (von Monakow's bundle), the tectospinal, the vestibulospinal and the bulbospinal.

Pyramidal Tracts.—The first three, the pyramidal tracts, belong to the motor system. Their cell bodies are located in the motor cortex of the brain. The axons from the cells pass through the white matter of the centrum semi-ovale, into the posterior limb of the internal capsule, thence into the cerebral peduncle and downward into the pons and medulla.

Crossed Pyramidal Tract.—At the lower part of the medulla, about the level of the inferior aspect of the inferior olivary body, the large majority, 84-86 per cent, of these fibers passes backward and to the opposite side, interlacing in a thick mesh, the motor decussation. We fix the dividing line between medulla oblongata and spinal cord at the lowest level of the motor decussation. In the spinal cord the fibers which have crossed in the medulla take a position in the posterior part of the lateral columns of white matter, and are there known as the crossed or lateral pyramidal tract.

Direct Pyramidal Tract.—The 14-16 per cent of motor fibers which remain on the same side as their cells of origin may be divided into the direct pyramidal tract, and the direct ventrolateral or Spiller's tract. The former, and more conspicuous of the two, retains its position, bordering on the anterior fissure of the spinal cord. It can be traced downward into the midthoracic portion of the cord where it usually disappears.

Spiller's Tract.—Spiller's tract splits off from the motor tract at a level of about the superior aspect of the inferior olivary body, although this line varies somewhat. Its further course is in the ventrolateral columns of white matter. Naturally, the motor neurons destined for an upper limb pass to the anterior cornu of the corresponding side, there to make synapse with the dendrites or cell bodies of anterior cornual nerve cells. The neurons of the direct pyramidal tract cross in the anterior white commissure most likely at the level of the segment in which they are going to end. We cannot say how Spiller's tract terminates, nor is it known whether it has any function differing from that of the other pyramidal tracts. It will be seen that apart from Spiller's tract all the axons from the motor cortical cells decussate before they come to their final synapse. This teaching is contrary to what obtained a few years ago when many held that the fibers of the direct pyramidal tract were distributed to anterior cornual cells of the same side.

Lesions of the Upper Motor Neurons.—The cell bodies in the motor cortex with their axons and their terminations are known as upper motor neurons. Therefore, it must be realized that this cell body-axon unit, may be short, as in the upper motor neurons to the oculomotor nucleus; medium, as in those to the cervical enlargement of the cord; or long, as in those to the lumbosacral enlargement. The important concept is that this upper motor neuron is a unit. It may be attacked in its cell body or anywhere along its axon, but so far as it be concerned, there are as a result what we shall term the cardinal symptoms of upper motor neuron lesion: (1) paralysis or weakness, (2) increased reflexes, (3) spasticity.

Paralysis or Weakness.—Concerning paralysis or weakness in upper motor neuron lesions it may be said that the degree of involvement determines the degree of weakness. Leaving out of consideration altogether the lesions of the cerebrum, pons and medulla oblongata, we may mention the following conditions in which the upper motor neuron system may be involved—trauma, neoplasm, hemorrhage, meningitis, myelitis and sclerosis. Of these, sclerosis is the only process which is ever likely to confine itself to the lateral pyramidal tract. All of the other conditions, although they may invade the pyramidal system, also usually invade other tracts as well, so that we fail to get a picture of upper motor neuron involvement unmixed with alien symptoms. The three usual

forms of trauma are stab wound of the spinal cord, an impact against the spinal column sufficient to cause a hemorrhage and a fracture-dislocation of the spinal column causing a crushing injury to the cord. Neoplasm of the cord might possibly be located in and limited to the crossed pyramidal tract but such a limitation would be unlikely. Tumor involvement, whether extramedullary or intramedullary, would by extension or pressure cause other symptoms besides those due to lesions of the upper motor neuron tract. Hemorrhage, like trauma, would hardly be confined to a single system. Meningitis usually involves the periphery of the cord and in course of time causes damage to the crossed pyramidal tracts. Myelitis is usually a diffuse process and, where not completely transverse, is quite irregular or chiefly found in a given area of blood supply; in any case myelitis is not limited to any definite tracts in the spinal cord. A true sclerosis of the lateral columns does occur, limited to the crossed pyramidal tracts and giving a pure upper motor neuron syndrome.

Where the lateral columns of the cord are involved in such a manner that the crossed pyramidal tract is damaged, the muscular weakness is commensurate with the damage. In a slow process like a chronic meningitis with the formation of radially disposed connective tissue bands which gradually compress the crossed pyramidal tract, the progress of muscular weakness is so slow that for a time it may escape the patient's notice. Finally, however, he will become aware that an act, such as getting up out of a chair, gives him considerable trouble, or in sitting down his legs may suddenly give way when he is a few inches from the seat of the chair. Naturally, the level of the spinal cord involved by the lesion determines the upward extent of this motor weakness; a tumor in the upper cervical region will give a quadriplegia of more or less intensity, while if it be situated in the midthoracic region, the upper limbs are normal and the picture is a paraplegia.

Increased Reflexes.—The reflexes whose arcs pass through spinal segments below the lesion are all exaggerated because of impairment or destruction of the reflex inhibitory mechanism from above. For instance, let us suppose there is an intramedullary glioma located at the lower part of the eighth and upper part of the ninth thoracic segment extending to both sides of the cord. In this case the biceps, triceps and scapulohumeral reflexes will be present and normal. The epigastric part of the abdominal reflex will be normal as the arc passes through the sixth and seventh thoracic segments. The midabdominal reflex will be lost when its arc is broken, but the inferior abdominal reflex as well as the knee jerks and Achilles tendon jerks will all be exaggerated; there will also be ankle clonus and Babinski reflex on each side.

Spasticity.—It is impossible to consider increased reflexes without postulating spasticity or *vice versa*. By spasticity is meant a hypertonic

condition of muscle groups, which hypertonicity is suddenly much increased and brought into play by passive or automatic movement of the part. To test for spasticity the patient should lie on his back; the examiner grasps the ankle with one hand and places the other beneath the patient's knee; then, without warning, he quickly raises the knee at the same time pushing the ankle up toward the buttock. If there be any great degree of spasticity, he will not succeed in raising the knee more than about fifteen centimeters in this double flexion. The limb will suddenly lock as though it were a single bone from hip to sole of foot. Lesser degrees of spasticity are not so easily demonstrated and much depends on the examiner taking the patient off his guard in the passive movements he uses. However, even though there be only slight involvement of the upper motor neuron system a certain amount of stiffness or resistance to passive movement will be demonstrated. The same symptoms can be developed in the upper limbs when the lesion is above the cervical enlargement, but for some reason we rarely find the spasticity as pronounced in the upper limbs as in the lower. It is always well to tell the patient that he must relax completely when you are testing for spasticity, otherwise many normal cases will at times unconsciously resist passive movement and the examiner may be misled. But the very effort to relax on the part of a conscientious patient has at times the following unfortunate result: We shall suppose that our patient has a slight involvement of the lateral columns but not enough to impair seriously the reflex inhibitory mechanism. The examiner grasps the ankle and flexes the thigh on the abdomen and leg on thigh and extends it again, repeating this a number of times in perfect rhythm. He is surprised to find no resistance to these passive movements. What has happened is this: The patient in trying to relax has augmented to the utmost what remains of his reflex inhibitory pathway and the rhythmic performance of the movements enables him to mask completely the spasticity. In such a case, not only must the movements not be rhythmic, but it will often be necessary to engage the patient in conversation in order to distract his attention and then suddenly to make the passive movement. In this way slight degrees of spasticity may be elicited which might otherwise easily escape notice.

The subject of spasticity has in recent years assumed a position of great importance from the surgical point of view, by virtue of Förster's suggestion of rhizotomy as a palliative measure. Affections of the upper motor neuron system, such as Little's disease, present the appalling picture of a patient, perhaps otherwise perfectly healthy and robust, a hopeless cripple in the lower limbs. The question of etiology in these cases is interesting, though somewhat speculative. In many instances the history of delayed and instrumental delivery is definite, and I think, therefore, the following observation is quite germane.

Hoche (7) showed that exsanguination in the human subject had a most decided effect so far as the possibility of faradic stimulation of the lateral columns of the spinal cord was concerned, a very few minutes sufficing, in the decapitated human subject, to render all efforts of faradization ineffective. In my own work on the dog (3) I confirmed Hoche's observations in this respect. Now, the immaturity of the myelinization of the crossed pyramidal tracts at birth is well known, and I would postulate, therefore, that this system would be, *ipso facto,* particularly vulnerable to any adverse condition. Let us now suppose that the delivery of an infant is prolonged and difficult, that instruments are used, and that prolonged artificial means are necessary in order to initiate breathing. In such a case one may assume that the circulation is brought almost to a standstill and what circulation of arterial blood obtains is deficient as far as its oxygen content is concerned, to say nothing of partial stasis and catabolic products. I submit that under such conditions, existing possibly for many minutes, a point of little resistance may well be the developing myeline sheaths of the crossed pyramidal tracts, and that certain chemical injury may be done at this time which precludes further normal development in these tracts, laying the foundation for a future sclerosis.

In spastic conditions like Little's disease, we may never hope to affect the cause; the only point of attack is the reflex arc. Should we cut the efferent limb, the motor roots or nerves, we should indeed obviate the spasticity, but leave in its place a much worse condition, flaccid paralysis with severe trophic disturbances. We may cut the afferent limb and, so doing, control the stream of afferent impulses, which normally flow into the spinal cord *via* the posterior roots even in complete relaxation—the impulses which account in large measure for normal tone and which are normally balanced in a perfect equilibrium by virtue of the reflex inhibitory mechanism.

Rubrospinal, Tectospinal, Vestibulospinal and Bulbospinal Tracts.—Concerning the *rubrospinal* tract it is surmised that its function is to bring the anterior cornual cells of the spinal cord and likewise the reflex arcs under the influence of the lateral lobe of the cerebellum. The *tectospinal* tract, binding the anterior part of the corpora quadrigemina to the anterior cornua of the cord, is supposed to serve as an agent in synergizing muscular action to visual impression. The *vestibulospinal* tract forms the bond of union between muscle action and sensory stimuli from the semicircular canals. The *bulbospinal* tract is practically unknown so far as function is concerned; but from its relation to the inferior olivary bodies and their relation in turn to the cerebellum it is possible that it plays a rôle in cerebellar synergy.

Lesions of the Lower Motor Neurons.—The cell body of the lower motor neuron is located in the anterior cornua of the spinal cord or in

certain areas of gray matter in the medulla, pons and mesencephalon. The axons of these cell bodies in the spinal cord pass forward and leave the cord, forming the anterior nerve-roots. Their further course through plexuses of segmental nerves to their termination in the muscles is too well known to require further description.

The function of the lower motor neurons is threefold: Motor, reflex and trophic. Later on the sympathetic content of the anterior root will be considered but this must not be confused with the lower motor neuron. Lesions of the lower motor neuron system give as their cardinal symptoms: paralysis or weakness, loss of reflex activity, flaccidity, atrophy and electrical reactions of degeneration.

Paralysis or Weakness.—As in the upper so also in the lower motor neuron system, the extent or severity of the lesion determines the amount of weakness, varying from a slight impairment to an absolute paralysis. The neuron may be invaded either at the cell body or in course of the axon. In the former case the causes may be tumor, hemorrhage, myelitis, acute anterior poliomyelitis, chronic anterior poliomyelitis, meningitis and disseminated sclerosis. The axonal involvement is confined to trauma, tumor and the neuritides.

A word of warning is not amiss when we consider the subject of neuritis. Usually in a true neuritis there is involvement of both afferent and efferent peripheral systems, but a motor neuritis and a sensory neuritis are not only possible, but occur often enough to be a serious obstacle to the diagnostician if not taken duly into account.

Loss of Reflex Activity.—Loss of reflex activity need not detain us longer than to call attention to the fact that the lower motor neuron forms the efferent limb of the reflex arc and consequently involvement will lead to diminution or total loss of reflex activity.

Trophic Disorders.—Trophic disorders follow damage to the lower motor neuron. Here again the trophic disturbance is commensurate with the gravity of the lesion and varies from slightly glossy skin to ulcers and destruction *en masse.* The physiology of trophic supply has been much disputed. There are those who consider that the anterior cornual cell alone presides over this function. To be sure prompt atrophy follows destruction of the anterior cornual cells, but trophic disorders also follow posterior nerve-root involvement, as in tabes dorsalis. Whoever has carefully read the work of Head and Rivers must have remarked that so long as Dr. Head's hand remained insensible to pin prick the sore just internal to the base of the first metacarpal refused to heal.

It is most likely that the reflex arc is largely responsible for trophic equilibrium. I would suggest that the normal stream of afferent impulses, chiefly protopathic but possibly also epicritic and deep, which flows into the spinal cord even during relaxation of the part, exercises a continual stimulation to the anterior cornual cells and by this activity

the cells perform the trophic function which is separate and distinct from the motor. The idea that trophic control is exercised through the medium of the sympathetic system (cells of intermediolateral tract, white rami communicantes, sympathetic cord, ganglion, gray rami communicantes) cannot be defended because in this case the atrophy or trophic sores would be in an entirely different region from that innervated by the anterior root in question. Again, though in severe trophic conditions the anterior cornual cells have been found degenerated, the cells of the intermediolateral tract from which come the axons for the white rami communicantes have been found in perfect condition.

Flaccidity and Hypotonicity.—The flaccidity and hypotonicity, as already described in the decerebrate frog, are directly dependent on the reflex arc, and, as in the question of trophic control, are found in sensory system diseases like tabes dorsalis, as well as in the pure lower motor neuron involvements.

Electrical Reactions.—Secondary to the loss of trophic influence and the ensuing chemical changes in the muscles, there appears what is known as the electrical reaction of degeneration. The muscle becomes non-responsive to faradic stimulation and the galvanic stimulation shows first; the cathodal closing contraction becomes equal to anodal closing contraction (C. Cl. C. = A. Cl. C.); finally the anodal closing contraction becomes greater than cathodal closing contraction (A. Cl. C. > C. Cl. C.). The first of these changes is spoken of as the *partial reaction of degeneration;* the second, as the *complete reaction of degeneration.* In literature this is abbreviated to R.D. For discussion of the electrical changes the reader is referred to works on the subject. Although trophic change seems to be dependent on both the afferent and efferent limbs of the arc, the reactions of degeneration usually follow involvement of the anterior cornual cells or their axons and not of the afferent limb.

Brown-Séquard Syndrome

Having considered afferent and efferent pathways in the spinal cord, we are now in a position to discuss the symptom picture due to a lesion of half the cord, the so-called Brown-Séquard syndrome. Let us bear in mind, however, the insecurity during the past fifty years of our knowledge concerning the spinal pathway of tactile sensation, and we shall not be surprised to find many contradictory statements bearing upon this much discussed subject, a point I have tried to emphasize earlier in the chapter when dealing with tactile sensation.

I shall classify the symptoms of Brown-Séquard paralysis under the following heads: (1) homolateral symptoms below level of injury; (2) contralateral symptoms below level of injury and (3) root-zone symptoms. Under the first two headings will be considered positive and

negative symptoms. By *root-zone symptoms* I mean the symptoms caused by the section of entering posterior roots within the spinal cord. If it be realized that posterior root axons on entering the cord have an oblique direction upward, it will be understood that at the level of section or lesion many heteromeric fibers will be cut causing a symptom picture quite at variance with what one finds several segments below. This zone lies at the upper limit of sensory disturbance and, according to the nature of the lesion, may vary from two or three centimeters in depth to a band of approximately ten centimeters. For instance, a hemisection from a stab-wound in which the spinal cord is cleanly incised by a sharp instrument will give a narrow root-zone picture, whereas, a fracture-dislocation or tumor involving half the cord may give a wide zone. Then again, even in stab-wounds, though primarily the root-zone picture may be narrow, yet with the extension upward and downward in the cord of traumatic softening the zone may in time become a wide band. One must be prepared for great variations in the root-zone picture; at times, the nicest care in the examination will be rewarded by uncertainty and doubt. In the following scheme it is postulated that the lesion is a cross-hemisection exactly to the anteroposterior diameter of the cord, a rare finding.

Homolateral Symptoms below Level of Injury

Positive	*Negative*
Paralysis of voluntary movement, at first, possibly flaccid, then spastic.	Preservation of thermal sense.
Loss of tactile sensation of varying degree, which may be temporary.	Preservation of pain sense.
Loss of pressure sense.	A possible partial preservation of tactile sense which in time may approach normal.
Loss of position sense.	
Loss of osseous sense.	

Contralateral Symptoms below Line of Injury

Positive	*Negative*
Loss of thermal sense.	Preservation of voluntary movement.
Loss of pain sense.	Preservation of pressure sense.
A possible partial loss of tactile sensation.	Preservation of sense of position.
	Partial or complete preservation of tactile sensation.

Root-Zone Symptoms

Homolateral	*Contralateral*
A zone of varying width in which all forms of sensation are lost.	The zone of complete loss of sensation fails, but there is likely to be a zone of hyperesthesia though it does not extend so high as on the homolateral side.
Above this there is likely to be an indistinct zone of hyperesthesia to all forms of sensation, due to increase in irritability of the tissue contiguous to the zone of injury.	

It will be seen that variations occur chiefly in the presence or absence of tactile anesthesia and experience has surely taught that *ex cathedra dicta* in this respect are impossible.

THE SYMPATHETIC SYSTEM

Lying on each side of the spinal column and extending from the skull above to the lower sacral region below are two cords of nervous tissue presenting at fairly regular intervals fusiform swellings which correspond in certain regions more or less to the levels of the intervertebral foramina. These cords and swellings, or prevertebral ganglia as they are called, are connected to the central nervous system by means of small branches, *rami communicantes,* from the anterior division of the common trunk of the spinal nerve. There are two distinct sets of rami communicantes, the white and the gray, and their origin and distribution are essentially different.

The White Rami Communicantes.—In the posterior and posteroexternal part of the anterior horn of gray matter of the spinal cord are cells the axons of which pass forward and leave the cord *via* the anterior roots, in company with the axons of the anterior cornual cells. After a short but variable distance, distal to the junction of the anterior with the posterior roots, to form the common spinal nerve, the axons of these cells leave the spinal system and pass to a ganglion on the sympathetic trunk. After joining the gangliated cord, the axons of the white rami may take one of two courses. They may pass either up or down the sympathetic cord ending finally in a sympathetic ganglion by breaking up into an arborization about a nerve cell of the ganglion; or, they may pass directly through the ganglion of entrance, or a nearby ganglion, and without interruption enter a collateral ganglion *via* one of the splanchnic efferent nerves from the sympathetic cord. On entering the collateral ganglion, they end in an arborization about sympathetic nerve cells. This system of fibers is spoken of by many as the preganglionic and it is well to bear in mind its close analogy to the lower motor neuron. Not all of the segments of the spinal cord furnish white rami communicantes, as may be seen from the diagrams. There are two systems of these fibers, the thoracicolumbar, from the second thoracic to and including the second lumbar segments and the sacral, from the second and third sacral segments. Above the second thoracic segment, between the second lumbar and second sacral and below the third sacral segment, there are no white rami.

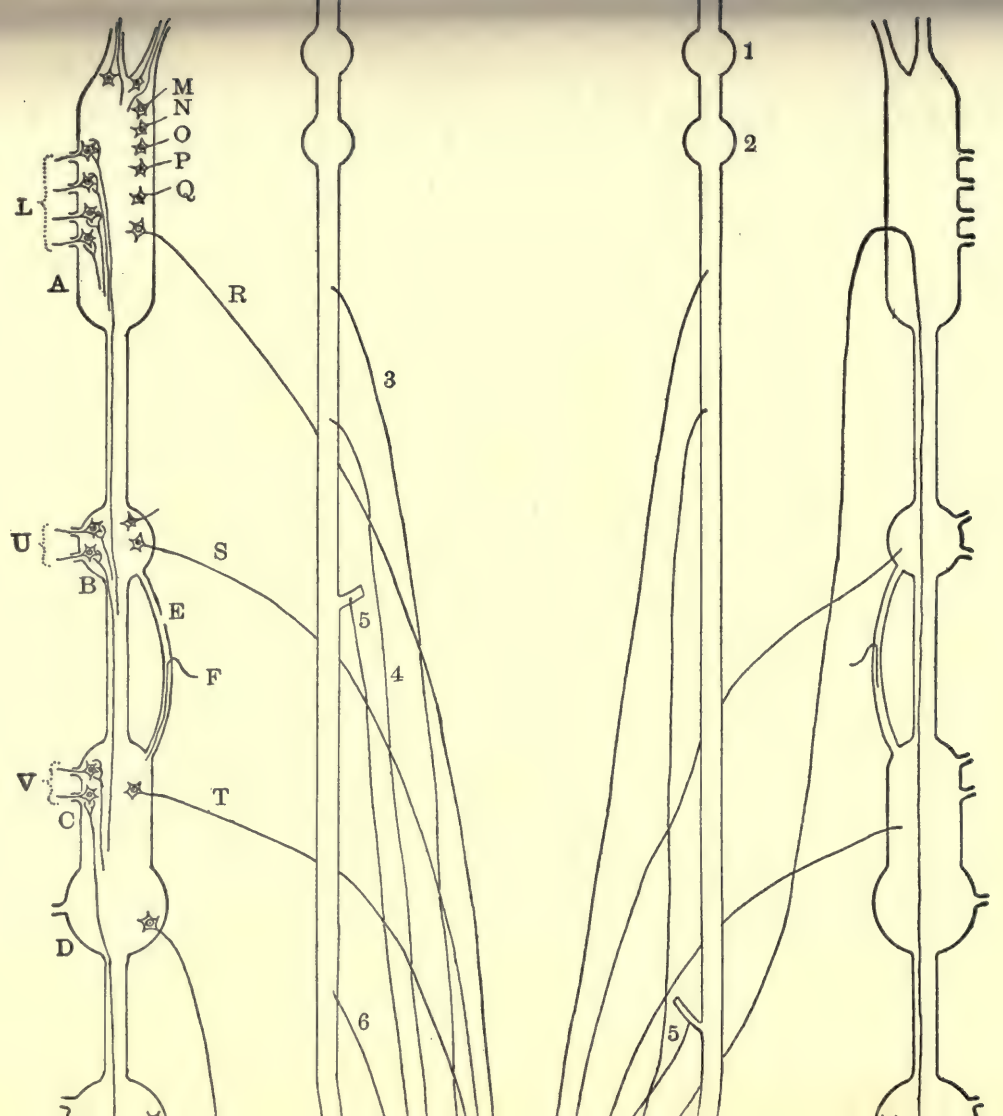
The Gray Rami Communicantes.—The nerve cells in the sympathetic ganglia give origin to axons which leave the ganglion of their origin or a nearby ganglion to join the common spinal nerve through the distri-

bution of which they reach their destination. Another course for the gray rami is *via* the splanchnic efferent fibers directly to their destination in a viscus. These rami form the postganglionic system. The terms *gray* and *white* were applied to the rami at a time when the former were supposed to be devoid of medullary sheaths, and the latter to possess these sheaths. There is no doubt that the content of medullated fibers in the white rami is far greater than in the gray, but recent refinements in technic have demonstrated very delicate medullary sheaths surrounding some of the fibers of the gray rami and one can no longer hold the presence or absence of this covering as a *sine qua non.*

Splanchnic Afferent System.—There is still to be described a most important system of fibers which, by virtue of the fact that it makes use of the sympathetic pathway as a convenient route from the periphery to the central nervous system, has been reckoned as an integral part of the sympathetic nervous system. I refer to the splanchnic afferent system. The cell bodies of these fibers are located in the posterior root ganglia and the pathway to the viscera is *via* white ramus, sympathetic ganglion (sympathetic trunk) and splanchnic efferent. Naturally the impulse travels in the reverse order. But it were well to bear in mind that these splanchnic afferent fibers are in no sense part of the sympathetic system; they are sensory fibers belonging to the posterior root ganglion and, as such, these are capable of transmitting sensory impressions and acting as the afferent limb of a reflex arc. It will be remembered that the number of cells in the posterior root ganglion is far in excess of the number of fibers entering the spinal cord from the ganglion in question. It may be, as suggested by Déjerine, that some of the sympathetic fibers of the posterior root do not enter the spinal cord, but transfer their impulse by a concrescence synapse to posterior root ganglion cells, but this has not been proved by any means. A relatively small number of splanchnic afferent fibers, the sensory supply of the spinal dura mater, may enter the gray rami and by this avenue reach the posterior root ganglion.

Distribution of System.—Sympathetic distribution is divided into the somatic and the splanchnic, the former depending on the gray rami content of the spinal nerves, the latter, on the splanchnic efferent system above mentioned. In this way are innervated unstriped muscular fibers as well as the secretory mechanism of glands, somatic and splanchnic.

As has been stated, the white rami communicantes are lacking in certain levels of the spinal axis, but this does not mean that there is no preganglionic content in the cervical sympathetic cord. By the experimental use of nicotin which paralyzes the preganglionic-postganglionic synapse, it has been determined that many if not most of the white rami of the upper five thoracic segments turn upward and, besides furnishing the preganglionic—for the somatic postganglionic fibers from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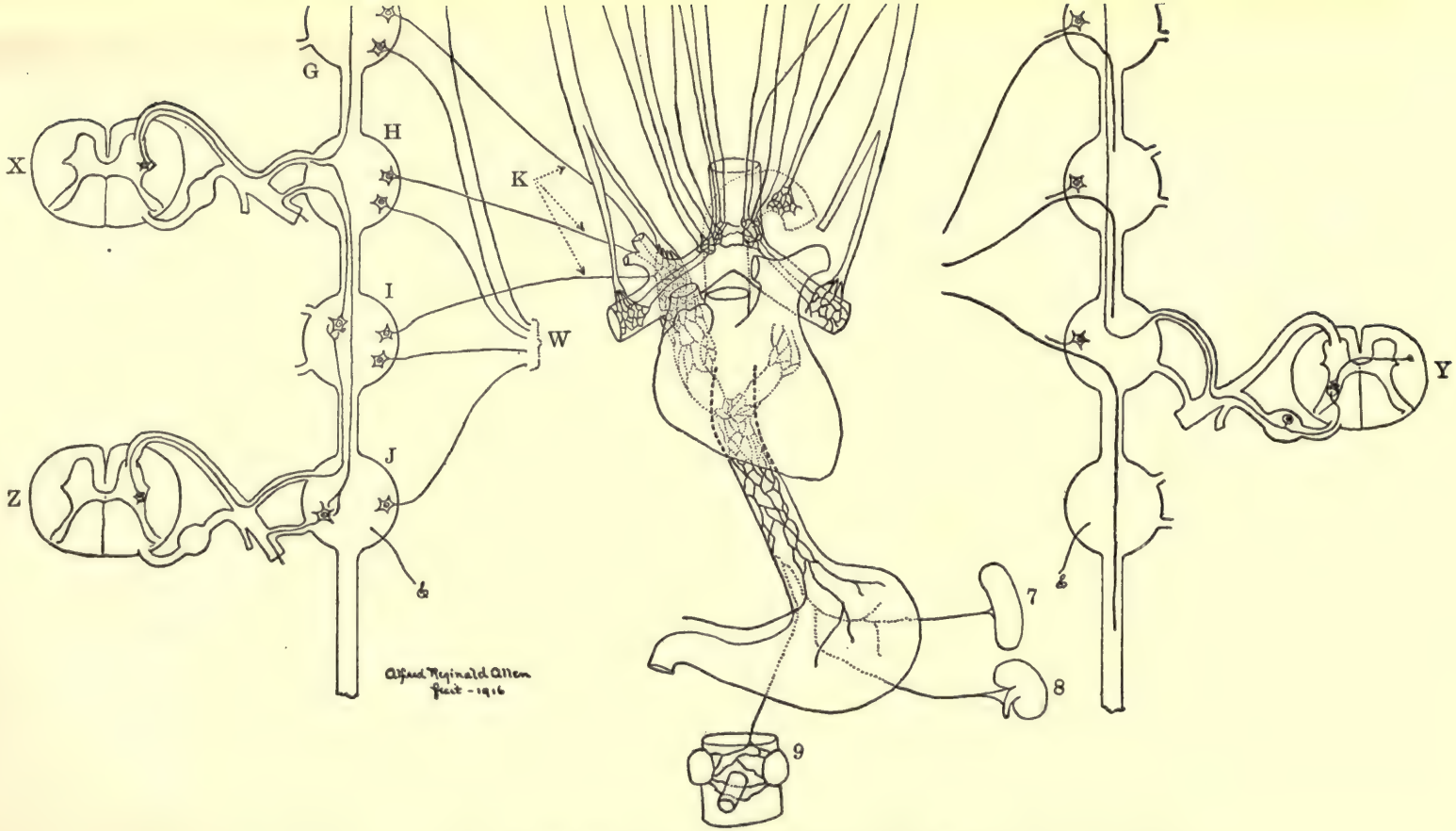


CHART I.—THE SYMPATHETIC AND PNEUMOGASTRIC SYSTEMS.

A, Superior cervical ganglion; B, middle cervical ganglion; C, inferior cervical ganglion; D, first thoracic ganglion; E, ansa subclavia; F, branch to subclavian plexus; G, second thoracic ganglion; H, third thoracic ganglion; I, fourth thoracic ganglion; J, fifth thoracic ganglion; K, branches to posterior pulmonary plexus; L, gray rami to first four cervical nerves; M, to petrous ganglion of N. IX. N, to jugular ganglion of N. X. O, to ganglion nodosum of N. XI. P, to N. XII. Q, to ascending pharyngeal plexus; R, superior cardiac nerve; S, middle cardiac nerve; T, inferior cardiac nerve; U, gray rami to fifth and sixth cervical nerves; V, gray rami to seventh and eighth cervical nerves; W, rami aortici; X, third thoracic segment; Y, fourth thoracic segment, illustrating pathway of cardiac pain; Z, fifth thoracic segment; 1, jugular ganglion of vagus; 2, ganglion nodosum; 3, superior cardiac branch; 4, inferior cardiac branch; 5, cardiac branch from recurrent laryngeal nerve; 6, thoracic cardiac branch; 7, splenic connection; 8, renal connection; 9, celiac ganglia and plexus; &, to great splanchnic nerve.

the upper thoracic sympathetic ganglia—also furnish the two, at times three, cervical sympathetic ganglia with their preganglionic connections. The gray rami are furnished to every spinal nerve without exception. When it is realized that there are no white rami above the second thoracic segment, it becomes evident that the spinal centers for vasomotor function of the head, neck, upper part of thorax and upper extremities must be located in the upper thoracic cord and those for the abdomen and lower extremities in the lower thoracic and first two lumbar segments.

To Langley belongs most of the credit for what there is of order in our present day concept of the sympathetic nervous system. The accepted teaching on this subject of the latter part of the nineteenth century was certainly "without form and void," but let it not be thought that to-day the question is solved. As a natural consequence of Langley's work has appeared the theory of vagotonia and sympatheticotonia, recently pictured in a clear and comprehensive article by Wolfsohn (17). But there are so many anatomical and physiological gaps yet to be bridged that the rather *ex cathedra* dicta fail to convince.

According to Langley the ganglia of the sympathetic are divided into the primary system or lateral ganglia, the secondary system or collateral ganglia and the tertiary system or terminal ganglia. The collateral ganglia include the coeliac, superior mesenteric and inferior mesenteric. The terminal ganglia include the plexus of Meissner and Auerbach and the small ganglionic collections in the viscera themselves. Concerning the terminal ganglia, Wolfsohn says (*loc. cit.*): "These (the plexuses of Auerbach and Meissner) have, as a rule, no connection with the fibers of the sympathetic system, but lie on the course of impulses descending by other nerves of the vegetative system, for example, the vagus or . . . visceral nerves." Now, there is no adequate proof that these plexuses have not a connection with the sympathetic, neither is there proof that they are "on the course of impulses descending by . . . the vagus." As a matter of fact we know neither the physiology nor the anatomy of these plexuses and any opinion thereon is speculative.

Langley, Wolfsohn, *et al.*, describe as the cranial and sacral autonomic system, collectively spoken of as the vagal system, certain visceral fibers of the oculomotor, trigeminal, facial, glossopharyngeal and vagus nerves together with the nervi erigentes. Here we are supposed to find the sympathetic prototype of the preganglionic and the postganglionic fiber. Fortunately it can hardly be considered as of the *res gestae* to deal in a work on the physiology of the spinal cord with any of the cranial nerves save the pneumogastric. Concerning the nervi erigentes if one considers them homologous to white rami communicantes and admits that we are not altogether certain as to their action, it becomes difficult to classify them as vagal.

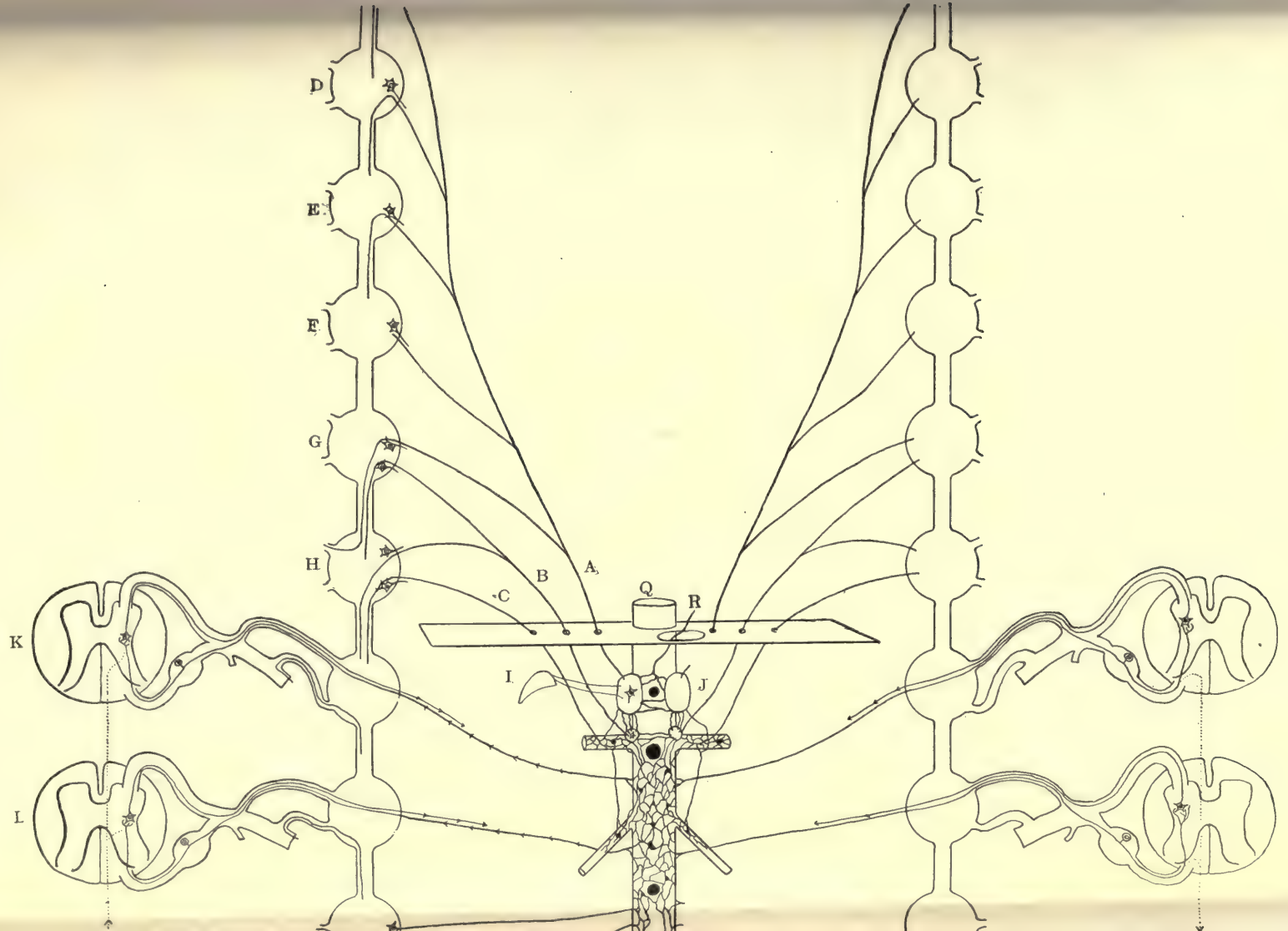
The intimate association of the sympathetic and the pneumogastric in

the esophageal, pulmonary, cardiac and gastric plexuses may be seen in the diagram. It must be borne in mind that not only are efferent systems present in these plexuses but also that splanchnic afferent and vagal afferent systems are represented. But the chief cardiac effect of vagus stimulation is inhibition, and this is made manifest when one vagus is divided and either the peripheral or central end is stimulated. In the former case there is a direct stimulation of the vagal efferents; in the latter we have stimulation of vagal afferents and a transmission in the medulla of this afferent stimulus to the efferent fibers of the contralateral vagus—a pure reflex phenomenon.

In the white rami communicantes of the second, third and possibly the fourth thoracic segments are fibers which, entering their respective sympathetic ganglia, pass upward to end finally in the inferior cervical ganglion. Here they form a synapse with sympathetic ganglion cells whose axons find their way most likely by the inferior cardiac nerve to the deep cardiac plexus. We may consider this the preganglionic and postganglionic pathway of the cardio-augmentor nerve—the antagonist of the vagus. Now, let us remember the early abolition of reflex activity in cases of severe lesion of the spinal cord below the level of injury and also that there is not only a tendency for resumption of reflex activity in cases not too severely injured, but also a tendency for some of the spinal centers usually controlled from above to assume, under these conditions, a certain automatic function. Therefore, in a cord injury, let us say in the third or fourth cervical segment, there follows temporary fall of blood pressure due to vasomotor paresis (shock) and slowing of the pulse due to temporary setting aside of augmentor activity. But with the later assumption of automatism in the spinal centers of the white rami communicantes, including vasomotor and cardio-augmentor cells, vasomotor tone and blood pressure are more or less restored and, the balance between cardio-augmentor and vagus again obtaining, the pulse rate approaches normal.

Relation of Visceral Pain Areas to Cutaneous Sensory Nerves

We have discussed the subject of splanchnic afferents and called attention to the fact that they are homologous to the peripheral spinal sensory nerve fibers. Now it is a known fact that careful handling of a viscus in a sentient patient provokes no sensory perception; but, stretching, squeezing or tearing produces pain not referred to the viscus, but projected, as it were, to a cutaneous surface of the body. The subject of visceral pain areas has been carefully worked out by Head and others. A physiological hypothesis to cover this phenomenon may be advanced as follows: The functional threshold of splanchnic afferents may be such that normally their afferent stream of impulses perform their work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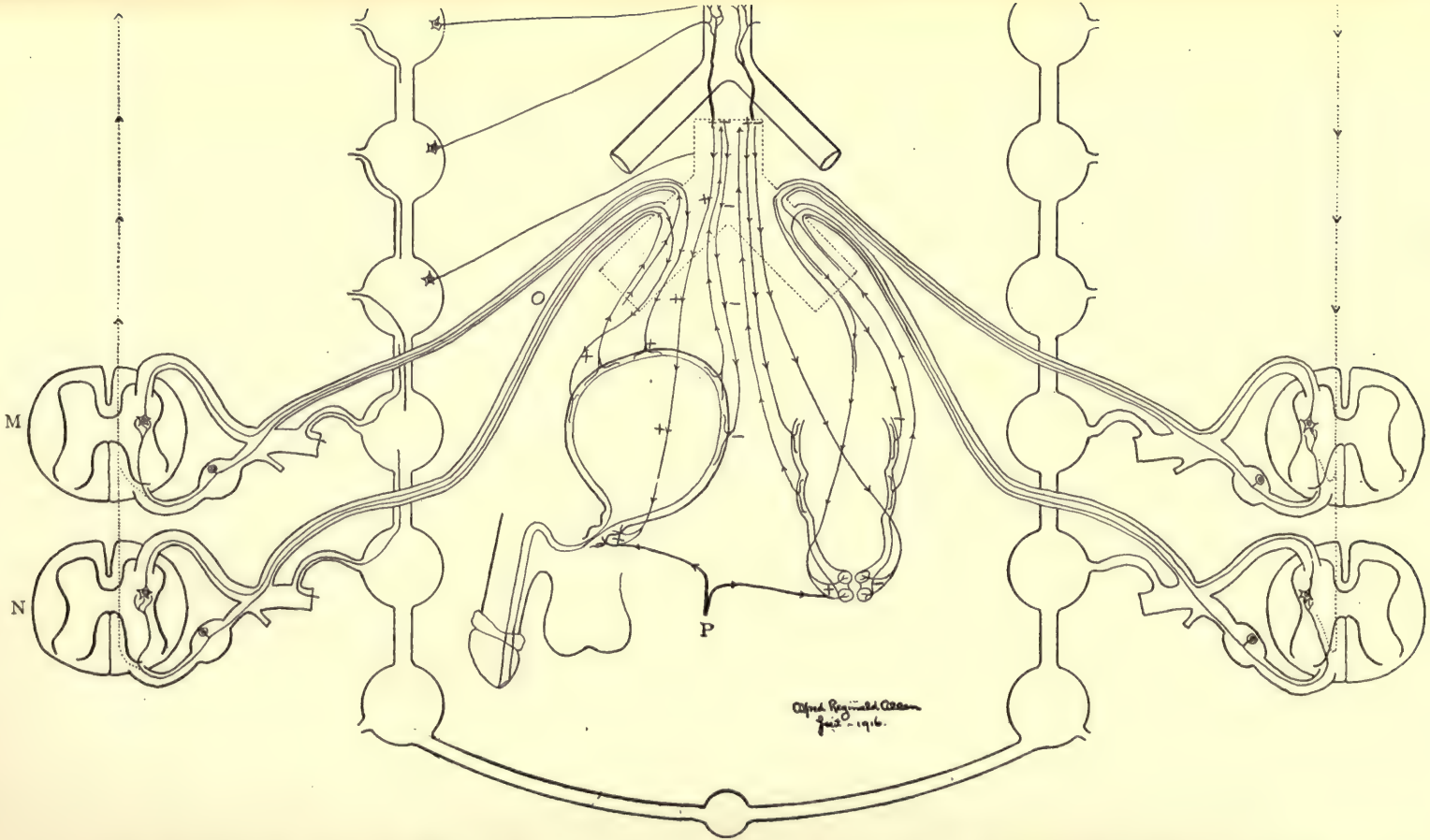


CHART II.—THE SYMPATHETIC AND PNEUMOGASTRIC SYSTEMS.

A, Great splanchnic; B, lesser splanchnic; C, least splanchnic; D, E, F, G, and H, sixth to tenth sympathetic ganglia; I, suprarenal body; J, celiac ganglia and plexus; K, first lumbar segment; L, second lumbar segment; M, second sacral segment; N, third sacral segment; O, nervi erigentes; P, pudendal innervation; Q, aorta; R, opening in diaphragm for esophagus.

There are many anatomical and physiological points in this diagram which are not marked because thoroughly obvious. The plus and minus signs indicate stimulation and inhibition respectively. The reciprocal innervation of bladder and rectum may be traced easily by means of the indicated fibers and their signs.

without transmitting to the sensory system of the spinal cord any impulses that register as conscious perception. But let the stimulus in the viscus be grossly excessive, one can then picture the possibility of stimulation in the posterior spinal ganglia which would result in a segmental referred pain. In the case of the heart such stimulation gives rise to pain in the upper precordium and down the inner aspect of the left arm, a well-known symptom of angina pectoris, in which the excessive splanchnic afferent impulses have had a supernormal action on the posterior spinal ganglia of the second, third and fourth thoracic segments.

Other Reflexes of the Sympathetic System

Reflex Mechanism in Tabetic Crisis.—In cases of tabes dorsalis one of the most distressing symptoms with which we have to deal is the tabetic crisis. These crises are of various types, among which we may mention the laryngeal, gastric, hepatic, intestinal and kidney and bladder variety. The gastric crisis, because of its relative frequency, is the most important for our consideration. Not all tabetics have crises, nor does the crisis make its appearance at any particular stage of the disease. Many cases have been operated upon for gastric ulcer, in which the diagnosis of locomotor ataxia has never been suspected, only to prove negative in regard to local gastric lesion. Later on such a case is correctly estimated when some striking symptom of tabes, such as Argyll-Robertson pupil or loss of knee jerks, presents itself. In other cases the disease may have developed conspicuously, presenting many of the classical signs and only at a late stage suffering from the crisis. Of course, in this respect, the crisis takes its place with the other symptoms of tabes and we realize that no law can be formulated as to the initial symptom or the sequence of symptoms in this disease. The following case will picture the typical gastric crisis:

The patient, a male, *aet.* 42, was infected with syphilis at 21 years of age. There ensued a brief and desultory anti-syphilitic treatment, and according to his accounts, the secondary manifestations, if any, were very moderate. At about 40 years of age he consulted an ophthalmologist for a slight failure in vision which he attributed to natural causes incident to his time of life. At this examination there was found a slight pallor of each optic disc and little, if any, iridic reaction to light. Shortly after this he began to notice instability in walking, particularly at night time, and he also suffered from shooting pains in his legs which he attributed to rheumatism.

He consulted me on account of "acute attacks of indigestion" which he was experiencing every two or three weeks, and which, so far as he could tell, were not associated with any dietary indiscretion. These attacks came on with great suddenness, the first symptom being a severe

cramp-like pain in the epigastrium which increased in intensity and in a few minutes was followed by vomiting. The vomitus was moderate in amount and was not characterized by extreme sourness or offensive odor. For a few minutes after vomiting there would be an amelioration, not a cessation, of pain and then another attack of vomiting with increased pain, which, by this time was sharp and lancinating. In the early part of these seizures he would be completely doubled up in his agony, screaming with the pain and covered with a profuse sweat. There might be remissions of fifteen minutes during which he would be comparatively easy; at these times he would relax in utter exhaustion. But without warning the pain would again attack him accompanied by unproductive retching or the vomiting of a little clear or bile-stained froth. These attacks would last for from two hours to a day and a half, and often would only give way to several hypodermatic administrations of morphin sulphate. After the crisis had been in operation a half or three-quarters of an hour there would be an extremely sensitive band of hyperesthesia about four inches in width around the trunk from the ensiform cartilage to within about two centimeters of the umbilicus. This zone would be so exquisitely painful to touch that I found him on a number of occasions naked on his bed, without even a sheet over him. The end of the crisis would come almost as abruptly as the onset, leaving him completely exhausted. Such is a fair description of a tabetic gastric crisis which may last for a number of days and, through extreme exhaustion and lack of nourishment, may bring a fatal termination.

Physiology of Gastric Crisis.—In considering the physiology of gastric crisis let us remember the following points: It is likely there are no afferent fibers from the stomach in the pneumogastric nerve; in cases dead of locomotor ataxia, in which gastric crises were a prominent symptom, histological examination has failed to find any pathological change in the stomach which might account for the phenomenon; in locomotor ataxia the initial lesion is in the posterior root ganglia. Let us suppose that the toxin of tabes has affected the root ganglia of the seventh, eighth and ninth posterior thoracic roots. The splanchnic afferent supply of the stomach passes through the sympathetic cord by one of two roots: Either upward, into the posterior pulmonary plexus and then along the sympathetic nerves from the second, third and fourth thoracic sympathetic ganglia, from which ganglia the fibers turn downward to leave the gangliated cord by the white rami communicantes to the seventh, eighth and ninth thoracic spinal nerves from where they pass to their cell bodies in the corresponding posterior ganglia; or afferent fibers from the stomach pass through the communicating pathway between the stomach and the coeliac ganglia and plexus and then upward *via* the great splanchnic into the fifth, sixth, seventh, eighth, and ninth tho-

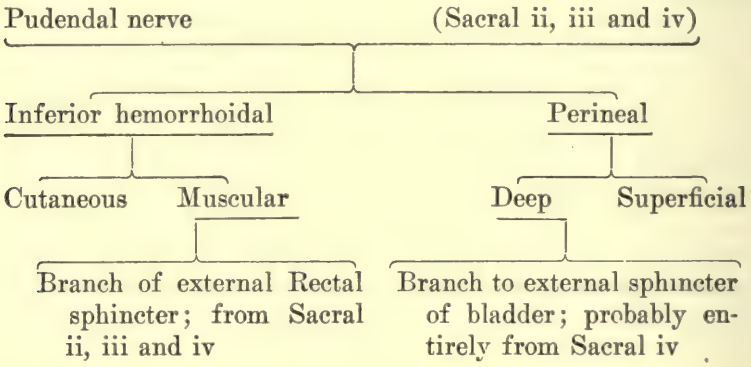
racic sympathetic whence they reach the white rami communicantes as above noted. In either case it now becomes evident why irritation of the posterior root ganglia of the seventh, eighth and ninth thoracic nerves may cause pain referred to the stomach. What is the further physiological explanation of the vomiting and why do the pain and vomiting cease after a certain period? To understand these questions we must realize that here we have to do with a reflex arc possessing an afferent (splanchnic afferent) and an efferent limb (vagus). The further pathway of the afferent impulses after entering the spinal cord is upward into the medulla where they make synapse with motor cells of the vagus, down which pass the efferent impulses. This accounts for the vomiting. The *quasi* periodic nature of the crisis may be accounted for by allowing that the amount of toxin present varies in amount and that when a large amount of this hypothetical toxin is present there may be an action as above described in the posterior ganglia, which action subsides either when the toxin is reduced in amount or counteracted by some autogenous means. The possibility of a depression of the reflex activity due to excessive chemical action of the toxin on the posterior root ganglia in question must also be taken into account.

Surgical Treatment.—Two surgical methods have been devised for meeting the question of gastric crisis. One is the cutting of the afferent limb, the other is the division of the efferent limb. The latter method is indefensible and dangerous; the former is a relatively simple procedure in which the posterior roots of the seventh, eighth and ninth thoracic nerves are cut proximal to the ganglia. This has proved efficacious in a number of instances. In those cases but little influenced by this procedure the difficulty may be that a certain number of the splanchnic afferents enter the cord above and below these segments with the result that an operation limited to these three sets of posterior ganglia still leaves sufficient afferent neurons of the reflex arc to produce the symptoms. In such cases a second operation in which additional roots are cut is indicated.

Bladder and Rectal Reflex Mechanism.—There are few questions more fundamentally important from a physiological and clinical standpoint than the reflex mechanism of the bladder and rectum; and I think one may truly state that relatively few physicians have more than a most inadequate concept of these all-important functions. The reason for this ignorance is not difficult to explain. For more than a generation physiologists have been at variance as to the mechanism of micturition and in 1901 Müller (12) drew a very general attention and approval to a theory that the reflex centers for the bladder and rectum were located extraspinally in the hypogastric and hemorrhoidal plexuses of the sympathetic. But prior to Müller's hypothesis, careful work had been done by Rehfisch, Mosso and Pelacani, and other investigators whose results

are of the greatest value to-day when the theory of Müller is passing into the position of historical interest.

Physiology of Bladder and Rectal Nervous System.—The sphincters of both the bladder and rectum are two in number, internal and external. In each case the internal sphincter involuntary muscle tissue receives its innervation from the sympathetic system: the internal vesical sphincter, from the hypogastric nerves, through the hypogastric and pelvic plexuses; the internal rectal sphincter through the nervi erigentes. The external sphincters which are voluntary receive their innervation from the pudendal as well as from the sympathetic. The origin of voluntary sphincter control may be well seen in the following scheme:



The normal condition of the internal sphincters of the bladder and rectum at rest is one of tonicity. Concerning the external sphincters of these organs it is more conservative to say that they are in a state of semitonicity.

Normal Reflex of Bladder and Rectum.—Let us now turn our attention to the urinary bladder and suppose that the ureters are delivering urine from the kidneys at a normal rate of flow. Like all unstriated muscle tissue the bladder possesses the characteristic that, if the stretching be very gradual, a maximum degree of stretching is possible before a reflex contraction is brought about. Therefore under the condition where the urine is very gradually increased in the bladder, a pressure of 150 mm. of water can obtain without causing any reflex vesical contraction. This will average in the adult male bladder from 230 to 250 c.c. Although micturition does not obtain with a 150 mm. of water pressure, yet when 120 mm. pressure has been reached, afferent impulses of two types pass from the bladder directly or indirectly to the central nervous system. The first type is for reflex activity and is twofold: (1) Afferent impulses upward *via* the epigastric nerves, inferior mesenteric plexus, splanchnic afferent—efferent branches to first and second lumbar sympathetic ganglia—and white rami communicantes to

first and second lumbar segments of spinal cord. At this level an efferent mechanism is brought into action, and traversing the same pathway in the opposite direction the internal (possibly also the external) sphincter is thrown into increased tonus, and possibly an inhibitory action exerted on the wall of the bladder; (2) afferent impulses from the bladder wall *via* the nervi erigentes to the second and third sacral segments, where under an existing inhibition to the act of micturition they may reënforce the higher reflex activity of the first and second lumbar segments. Without this inhibition, these afferent impulses from the bladder wall through the nervi erigentes would have excited a reflex contraction in the bladder and an overcoming of the sphincter action. The second type of afferent impulse accounts for the painful sensation of the distended bladder and the possibility of pathways of transmission may be given as follows: Afferent impulses from bladder wall to first and second lumbar segments of spinal cord, *via* the hypogastric plexus and nerves as above described, from which segments, upward, the impulses travel as do impulses for pain stimuli. The reception in the brain of these painful sensations is provocative of a dual function: (1) A cerebral voluntary impulse to the fourth sacral segment calling into action the anterior cornual cells of the fibers in the deep branch of the perineal nerve to the external sphincter; (2) an augmentation of the inhibition of the bladder wall, as above noted. Now let us suppose that the pressure in the bladder has become excessive and the pain unduly prominent. If under these conditions the act of micturition be convenient, the voluntary contraction of the external sphincters is relaxed and the inhibition to the bladder wall through the hypogastrics is overcome by the now much stronger afferents through the nervi erigentes and there is a contraction and emptying of the bladder.

When the filling of the bladder is rapid a relatively smaller amount of urine sets the reflex in operation. Fifty cubic centimeters of fluid injected into the bladder may cause the reflex.

It will be noticed that I have said nothing about contraction of the muscles of the abdominal wall with consequent raising of vesical pressure. In the example noted it is postulated that the distention of the bladder is excessive and therefore additional rise in pressure is unnecessary. All that is needed is the voluntary relaxation of the external sphincter and the cessation of the bladder wall inhibition and the act of micturition takes place reflexly. On the other hand should it be deemed necessary to empty the bladder and the adequate amount of urine to produce sufficient afferent stimulation not be present, then the subject makes voluntary contraction with the abdominal muscles, closing the glottis and fixing the diaphragm. In this way the reflex is started and continues until the act is complete. With a full or distended bladder the subject does not normally contract the abdominal muscles, as such action only causes in-

creased pain. To be sure, in the aged the reflex may be hard to start and the subject may experience a really high degree of suffering before the flow is established.

We now come to the reflex of defecation. An examination of the diagram will show that the mechanism is just exactly reversed from that of micturition. In defecation the tonic condition of the sphincters is preserved by the nervi erigentes, while contraction in the rectal wall is evoked by means of the hypogastric and pelvic plexuses. As in the case of the bladder, so also in the rectum, distention causes inhibition of the mechanism, until such time as it may be conveniently exercised, as well as pain and voluntary strengthening of the action of the external sphincter.

From these considerations it becomes evident that a lesion of the spinal cord which cuts off the afferent pathway of the bladder and rectum to the brain, eliminates the voluntary contraction of the external sphincters and the exercise of the high inhibitory action on the bladder or rectal wall. There is also an inability to raise the intravesicular or intrarectal pressure by contraction of the abdominal muscles and diaphragm. On the other hand the pelvic reflex mechanism is free from all inhibitory control from above and as soon as either organ is sufficiently distended the reflex contraction takes place and we have the condition of involuntary micturition or defecation.

If we remember the automatic depressor effect of an antagonist reflex arc action and also note that in the bladder and rectal mechanisms we have a reciprocal relationship, we shall not need for an explanation of an interesting phenomenon concerning micturition and defecation. In the human subject the greater afferent stimulation determines which mechanism, micturition or defecation, shall be first set in action. That mechanism having the lesser amount of afferent stimuli will be automatically inhibited until such time as the former reflex is partially or completely terminated. This phenomenon is demonstrated by the fact that if the afferent impulses from the bladder be the more intense the act of micturition takes place and only when this reflex is concluded or nearly so, does the reflex of defecation start, the reverse holding true when rectal stimuli predominate.

Disorders Due to Lesions of Spinal Nerves.—From the above discussion of the physiology of the bladder and rectum it will be understood that in a complete traumatic lesion of the spinal cord above the first lumbar segment, the reflex activity would be suspended, at least for a short time, and a distended bladder would be passively partially emptied, as might also the rectum, were the fecal material of liquid or semi-liquid consistence. As there is a greater tendency to the automatic restoration of the involuntary muscular systems governed by the sympathetic, after the initial period of relaxation was passed there would possibly be a restored tonus in the internal sphincters of the bladder and rectum, but

this would not be so strong a barrier to pressure as if the external sphincter were under the control of the will. Sensory impressions of distention would not reach consciousness and therefore the pudendal mechanism would not be voluntarily brought into play. Nevertheless, many cases show a restoration of pudendal reflex and for a time a weakened action of the efferent impulses from the nervi erigentes and hypogastrics. In such cases we are met by a condition of obstinate retention. At times there is seen a condition in which the reflex activity is permanently lost, leading to a continual dribbling of urine, and in the case of the rectum to obstipation or paralytic incontinence according to whether the feces are solid or fluid. Why this latter condition can permanently obtain with a lesion above the lumbar cord is hard to explain. In the lower animals I have seen it many times where there has been an experimental lesion of the midthoracic segments. In cases of destruction of the conus and epiconus paralytic incontinence of urine and feces is the rule. From the diagram one might suppose that the hypogastric mechanism would keep the bladder shut; but it must be realized that this innervation concerns the internal sphincter and at best there would be an overflow dribbling incontinence. As a matter of fact even in these cases the internal sphincter in time loses its tonus.

As we deal with reflex arcs in bladder and rectal mechanism it will easily be understood that destruction of afferent or efferent limb will destroy the reflex. Therefore, in tabes dorsalis where the posterior ganglia of the lumbosacral cord are involved there is a blocking of afferent impulses from the bladder and rectum. The patient often does not feel the necessity for urination and the afferent impulse never reaching the efferent neurons of the hypogastric mechanism or nervi erigentes there is disturbance of function, characterized at first by distention and difficulty in starting the stream, and later by atony in the sphincters with consequent dribbling incontinence. This condition is at times referred to as anesthesia of the bladder and rectum and its pathology is analogous to that of gastric crisis in that the point of attack lies in the posterior ganglia through which pass the neurons of the splanchnic afferents from the bladder and rectum.

Pathological Reflexes Due to Lesions of the Conus, Epiconus and Cauda Equina.—We have considered the general principles of lesions of the spinal cord involving upper and lower motor neurons as well as the grouping of sensory or afferent neurons within the spinal cord. It remains to call attention briefly to certain syndromes dependent upon lesions of given levels which while not involving any principles not already completely covered, yet might well be recapitulated as entities.

Differential Diagnosis.—The necessity of differential diagnosis between lesions of the conus and epiconus, on one hand, and the cauda equina, on the other, rests on the fact that in the former cases surgical inter-

ference is contraindicated while in the latter much may frequently be accomplished. Unfortunately, this differential diagnosis is not always easy or even possible, but the following points should be considered and on them differential diagnosis is often secured: (1) On account of the space between the bony canal and the cord from the twelfth thoracic vertebra downward, and particularly on account of the space and free mobility of roots below the conus (*vide* diagram) any sudden onset of symptoms in a non-traumatic case may be safely ascribed to a lesion of the conus itself; (2) as might be expected from the principles of intramedullary lesions, the great preponderance of pain and other symptoms argue in favor of lesion of the cauda equina; (3) lesions of the conus as a rule do not cause radiating pains down into the lower limbs; the reverse is the condition in involvement of the cauda equina; (4) symmetrical anesthesia with early and pronounced atrophy, electrical reactions of degeneration and decubitus point to lesions of the conus or epiconus; (5) asymmetry in anesthesia and variations from time to time in the symptom picture speak for lesions of the cauda equina; and (6) naturally, a lesion of the spinal column below the second lumbar vertebra in the adult can cause involvement of the cauda equina only, but in little children where the level of the end of the conus is relatively lower in the spinal canal, due consideration must be given to the possibility of involvement of cord substance.

Lesions of the epiconus give the picture of degeneration, flaccid paralysis of muscles receiving innervation through the peroneal nerve, with a spastic paralysis accompanied by reflexes of muscles whose afferent and efferent supply comes from segments below the epiconus. The anesthesia of such a case will correspond to a distribution of all spinal nerves below and including the fifth lumbar segment.

In injuries of the sacrum involving the *cauda equina* the symptom picture depends on the level of injury. The lower the involvement in the sacral canal, the fewer roots will be injured, and the more will the flaccid paralysis and anesthesia be confined to the low sacral roots. Let us suppose that the lower part of the sacrum is injured below the exit of the third sacral nerve; in such a case there will be lack of bladder and rectal control due to destruction of the pudendal mechanism of the external sphincters, and there will be an area of anesthesia about the anus extending backward to the sacrococcygeal articulation and forward to the base of the scrotum in the male or the posterior two centimeters of the vulva in the female. Cutaneous sensation of the scrotum is subserved by the third sacral segment, but the question of testicular sensation is much more complex, and any statement concerning its physiology must be made with reserve. It is possible that splanchnic afferent fibers from the testicle pass by way of the pelvic and hypogastric plexuses to the upper lumbar sympathetic ganglia, and from there *via* the white rami communicantes

into the upper lumbar segments of the spinal cord. It is well known that there is no parallelism between cutaneous scrotal anesthesia and loss of testicular sensation. The latter is frequently seen in tabes dorsalis.

In lesions of the *lumbosacral cord* sexual power is frequently lost or impaired because of lack of erectile mechanism or disturbance of ejaculatory function or both. The physiology of the phenomena of erection and ejaculation is complex and interesting. Afferent impulses from the penis pass by way of the pudendal nerve to the posterior roots of the second and third sacral segments. On entering the spinal cord these impulses have two objectives: one pathway leads up to the brain and through it pass impulses which are recorded in the brain as erotic sensation; the other pathway leads to the nerve cells of the second and third sacral segments whose axons pass out *via* the nervi erigentes. By these means the blood spaces in the erectile tissue of the penis are dilated and the phenomenon of erection is initiated. Psychic stimulation can accomplish the same condition without the aid of the pudendal afferents. When the sensory, psychosensory or psychic stimulation becomes sufficiently summated the ejaculatory phenomenon takes place; the latter is through the pudendal efferent fibers which are very likely postganglionic, through gray rami communicantes to the second, third and fourth sacral spinal nerves, the preganglionic fiber having its cell of origin in the first and second lumbar segment of the spinal cord. It now becomes evident that destruction of the lower sacral or upper lumbar cord means loss of erectile power or ejaculation. Lesions of the cord above the lumbar region eliminate the psychic element both perceptive and efferent. Posterior root ganglion disease such as tabes dorsalis may destroy the pathway of afferent stimuli from the periphery and so weaken or paralyze sexual power.

I have discussed elsewhere (4) the semiflaccid turgescence of the penis in fracture-dislocation of the spinal column. This is without sexual significance and is probably due to reflex action on the nervi erigentes.

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CHAPTER III

THE CEREBROSPINAL FLUID AND ITS RELATION TO SPINAL DISEASES

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GENERAL CONSIDERATIONS

While the cerebrospinal fluid has been for some time the subject of much research and many philosophical discussions among anatomists and physiologists, it is only recently—indeed, only since Quincke's epoch-making introduction of lumbar puncture in 1891—that its clinical importance has been recognized.

Since that time its field of usefulness in the diagnosis of the various pathological conditions of the cerebrospinal system has been constantly enlarging; the union between clinic and laboratory has become closer and closer. This is to be attributed largely to the elaboration of delicate tests and reactions for the detection of pathological changes in the fluid. Not only do we examine the fluid for (*a*) the physical changes, such as modifications in its amount, color, consistency and specific gravity, for (*b*) physiological changes, such as variations in pressure, and chemical abnormalities—particularly as regards protein and sugar content—but, owing to the work of the French scientists, Widal, Ravaut, Sicard and others, (*c*) cytological investigations have been instituted, and we are able to detect both qualitative and quantitative changes in the cells. Moreover, the discovery by Castellani of Trypanosoma gambiense in the fluid in sleeping sickness opened up still another and very important field of investigation, the bacteriological examination of the fluid; and through Plaut and others the Wassermann reaction has been applied to the cerebrospinal fluid for the detection of syphilis. These numerous methods of investigation have thrown much light on our understanding of organic diseases of the central nervous system, and are of inestimable value to clinician and surgeon. We need no longer base our conclusions upon one or two facts, but rather upon the data obtained through these various delicate and painstaking tests. Indeed, with few exceptions the diagnostic value of cerebrospinal fluid examinations is appreciated only after fairly thorough physical, chemical, bacteriological and serological studies, the total results being considered with the clinical manifestations of disease.

For example, certain changes, such as xanthochromia, slight or no cellular increase and markedly increased albumin, which form the so-called compression syndrome indicative of a space-restricting process in the spinal canal, frequently go hand in hand, and have come to be regarded as pathognomonic of certain pathological conditions. If, in addition to the compression syndrome, serological examination reveals a positive Wassermann, or bacteriological tests demonstrate one of the microörganisms common to a purulent meningitis, or the tubercle bacillus, then the exact nature of the space-restricting process is at once evident.

In order to understand and interpret aright the many pathological changes in the fluid which may be revealed by these various tests and reactions, one should have a clear concept of the cerebrospinal fluid under normal conditions, its anatomical and physiological relations and its physical, chemical, and cytological characteristics. In fact, it is only by a careful comparison of the normal and the abnormal fluid that we shall finally understand the true nature of many pathological processes of the cerebrospinal system. In spite of the research of the past few years, however, there are many questions in the anatomical and physiological relations and the chemistry of the cerebrospinal fluid which are still unsolved. Indeed, few facts in its physiology have yet been established beyond the peradventure of a doubt. Nevertheless, owing to the recent investigations of Frazier, Dixon and Halliburton, Mott, Dandy and Blackfan, Thomas, Cushing and Weed and others whom I might mention, our theories are beginning to crystallize and our ideas as to the origin, circulation, and absorption of the fluid are becoming clearer.

To no one are these advances of greater import than to the neurological surgeon, whether he be coping with lesions within the cranial cavity or the spinal canal. Yet their importance for the entire field of medicine is scarcely to be estimated. For example, it has been found that drugs and antisera injected into the cerebrospinal fluid act more quickly upon the tissues than when injected directly into the circulation—as has been proved by the work of Flexner, Swift and Ellis, and others in the field of intraspinal therapy. The time has come, therefore, when the cerebrospinal fluid has ceased to be a subject merely of academic interest and speculative theorizing and has become one of very practical moment to the clinician in the diagnosis of diseases of the nervous system and in the treatment of various infectious conditions, and to the surgeon in his attempt to deal more successfully with the problems of cranial and spinal surgery.

Anatomical Considerations in Regard to the Cerebrospinal Fluid.—While there are few facts to guide us in the early evolutionary history of the cerebrospinal fluid, it is probable that the earliest anatomists recognized the existence of fluid in the cerebral ventricles, although it was not then known to have any connection with the subarachnoid fluid. Galen

believed that the ventricles were in free communication with one another, but not with the outer space, and that the ventricular fluid contained the soul or animal spirit. In 1543, however, Vesalius discarded Galen's teachings, and described the fluid as a lubricant. It was later described by Valsalva (1764), who noted, upon cutting the spinal membrane in the dog, the escape of an ounce of fluid "similar to that found in the articulations," and in 1764 Cotuguo demonstrated the presence of fluid in the ventricles in the living animal. Cotuguo also affirmed the existence of a transparent fluid surrounding the nervous centers in the human cadaver. Its presence during life, however, was still doubtful, because of the firm belief in Haller's vapor theory.

Magendie was the first to realize the great physiological importance of the fluid which he called "cerebrospinal fluid," and we owe much to his extensive researches which were published in 1825, 1826, 1827 and 1842. Through his investigations, it was shown that under normal conditions both the ventricles and the subarachnoid space are filled with fluid, and that the fluid passes freely from the ventricles to the subarachnoid space through the foramen which has since been named for him. While certain of Magendie's views in regard to the physiology of the cerebrospinal fluid have been disputed by later workers, the existence and free circulation of the fluid has never been denied since the publication of his very comprehensive contribution to the subject in 1842.

Course of the Cerebrospinal Fluid.—Under normal conditions the cerebrospinal fluid circulates freely between the ventricles of the brain and the cerebral and spinal subarachnoid spaces, the principal means of communication being the foramen of Magendie at the apex of the fourth ventricle and the foramina of Luschka on the lateral aspects of the same ventricle. Magendie discovered that the passage of the fluid from the cerebral to the spinal subarachnoid space was synchronous with each cardiac systole—a fact which was afterwards corroborated by the experiments of François-Franck and others.

Origin of the Cerebrospinal Fluid.—It has been granted for some time that the choroid plexus is the principal source of the cerebrospinal fluid. The anatomical facts, the histological investigations, chemical analyses, physiological experiments and clinical data now at hand seem to indicate that this fluid, which has no analogy in the entire body, is, in the main at least, a true secretory product of the cubical cells of the choroid plexus. There are some, however, who still maintain that the cerebrospinal fluid is a transudate, or a product of dialysis from the blood plasma. We will, therefore, briefly review the arguments in favor of both its secretory and transudatory origin.

As early as 1664 Willis remarked upon the glandular nature of the choroid plexus, but it was not until 1853 that Faivre ascribed an active secretory function to the ependymal cells covering the choroid plexus,

thereby establishing a definite relation between them and the cerebrospinal fluid. The same theory was advanced by Luschka a few years later, and has since been strongly supported by the researches of Capelletti, Cavazzani, Findlay, Meek, Obersteiner, Pettit and Girard, and of Mott. Indeed, there has been little doubt that the cerebrospinal fluid was the secretory output of the choroid plexus since Pettit and Girard published their monograph in 1902 on the morphology and histology of the choroid plexus, based upon a study of the plexus in different classes of vertebrates and upon the histological changes in the plexus following the administration of substances with a hypersecretory effect. Mott has further strengthened the secretory hypothesis by a comparison of the lacrimal gland and the choroid plexus. Between the two he saw a marked similarity, and on the basis of his own histological studies and evidence from other sources he postulated that the choroid plexus was a gland with an external secretion but with an internal destination, a mixed type of gland, intermediate between a ductless gland and a gland with a duct, its formation being affected in an inverse manner—epithelial invagination for a gland with an excretory duct, ependymal invagination for the choroid plexus.

The *intra vitam* staining experiments of Francini, Bibergeil and Levaditi, Goldmann and others substantiate still further the secretory nature of the cerebrospinal fluid. Their findings have demonstrated not only the glandular character of the choroid plexus, but the presence of granules of a secretory nature. Goldmann, in his study of the fetal nervous system by *intra vitam* staining methods, found that intracellular glycogen was demonstrable only in the plexus cells. This substance, however, was not held back by the cells, but secreted drop by drop and diffused with the cerebrospinal fluid throughout the entire nervous system.

The importance of the cerebrospinal fluid as a nutrient agent will be considered later. Pettit and Girard, Meek, and others have also observed that the epithelial cells of the plexus undergo important changes under the influence of agents which stimulate secretion, the cells often being transformed into globules which merge with the cerebrospinal fluid.

Attempts have been made to demonstrate by chemical analysis that the cerebrospinal fluid is a secretion, not a transudate from direct filtration. In 1850 Schmidt called attention to the differences in chemical composition between the cerebrospinal fluid and the blood plasma and other serous fluids, showing that there was a much larger proportion of potassium salts in the cerebrospinal fluid than in lymph. It has since been demonstrated, however, by the analyses of Yvon, Müller, and Halliburton that the inorganic constituents of cerebrospinal fluid are almost identical, both qualitatively and quantitatively, with those of the blood plasma. On the other hand, the fact that the cerebrospinal fluid contains no true albumin, no fibrinogen, none or but very few leukocytes, no antibodies—as agglutinins or complements—and only a slight amount of protein in the form

of globulin, makes it evident that the cerebrospinal fluid is not a simple transudation. On the ground of the striking similarity between the inorganic constituents of the blood plasma and of the fluid, Mestrazat maintains that the cerebrospinal fluid is neither a secretion nor a transudation, but rather, like the aqueous humor, a product of dialysis from the blood plasma. Such a hypothesis can scarcely stand, however, based merely upon a similarity of inorganic contents, and without the support of histological evidence and physiological data, both of which are strongly in favor of the secretory origin.

Some of the strongest arguments in favor of the choroid plexus as the source of the cerebrospinal fluid are the results of the recent physiological investigations which have been carried on in the laboratories of Frazier, of Dixon and Halliburton, of Dandy and Blackfan, and others. It has been demonstrated quite conclusively by Frazier and Peet, and by Dixon and Halliburton that a decided increase in the flow of the cerebrospinal fluid follows the injection of choroid extract. The fact that Frazier and Peet, and Dandy and Blackfan were able to produce an experimental hydrocephalus by blocking the aqueduct of Sylvius seems also to point to the plexus as the source of the fluid. In one of their experiments Dandy and Blackfan also found that extirpation of the choroid plexuses considerably modified the degree of the internal hydrocephalus. Moreover, Hill's experiments have shown that in the closed craniovertebral cavity the pressure of the cerebrospinal fluid and of the capillaries is the same; hence, a filtration pressure would be impossible.

The impermeability of the choroid plexus, as shown by the experiments of Frazier, Goldmann and others, may be offered as further evidence in favor of the secretory theory. When foreign substances were injected into the circulation, the choroid plexus played the part of an impermeable filter and prevented their entrance into the cerebrospinal fluid, so that no untoward symptoms appeared, although the plexus was brightly colored by the dye. On the other hand, when the dye was injected into the subarachnoid space, the brain and cord were at once stained.

Thus the preponderance of the evidence, histological, chemical, and physiological, seems to favor the hypothesis that the cerebrospinal fluid is for the most part a secretory product of the choroid plexus. Can we, however, at this juncture deny the possibility of additional sources or of increments to the fluid from other channels? It may be possible that a part of the fluid originates from the tissues and vessels of the nervous system. Under conditions of high intracranial tension, Frazier has observed drops of fluid appear on the surface of the brain, as though the fluid came directly from the brain substance itself or from its blood vessels —an observation which Spina has also made in his experimental work. Indeed, if we agree with Mott's theory, that the cerebrospinal fluid as it circulates through the perivascular and pericellular canalicular system

serves as the ambient medium for the exchange of products between nerve cells and the blood, we must grant that the cerebrospinal fluid receives increments from both the nervous tissue and the blood *via* the perivascular system.

The question has arisen as to whether the cerebrospinal fluid may not receive increments from the ependyma, hypophysis or pineal. Kafka, in his uranium experiments, found that the greater part of the fluid was secreted by the choroid plexus, a little by the ependyma of the ventricles and central canal, while the tissues lining the subarachnoid space showed no signs of secretion. Fuchs and Francini have also observed evidences of secretory function on the part of the ventricular ependyma. We can still only conjecture as to the possibility of accessions from the pituitary and pineal. Cushing and Weed assumed that the hypophysis contributes to the cerebrospinal fluid because the posterior lobe extract accelerates the flow. These questions cannot be finally determined, however, until we are able to ascertain whether the fluid in the ventricles is identical with that in the subarachnoid space chemically, physically and cytologically.

Certain of the recent investigators—particularly Weed, Plaut, Rehm and Schottmüller, and Hauptmann—concede that the greater part of the fluid is secreted by the choroid plexus, but that some is derived from the perivascular system of the nervous tissues, and their evidence is so convincing that it seems to me, for the time at least, we must grant that the cerebrospinal fluid is mainly a secretory product of the choroid plexus, though a small part at least may originate in other structures.

Absorption of Cerebrospinal Fluid.—In spite of the work of Cathelin, Flatau and a few others who have emphasized the importance of lymphatic absorption, the great preponderance of evidence indicates that the greater part of the fluid leaves the subarachnoid space *via* the venous circulation rather than the lymphatics, the lymphatic absorption being slow, roundabout, and relatively diminutive. This statement is substantiated by the investigations of Key and Retzius, Reiner and Schnitzler, Hill, Ziegler, Sicard and Cestan, Frazier and Peet, Cushing and Weed, Mott, and of Dandy and Blackfan. When phenolsulphonphthalein is injected into the ventricles, it appears, according to Frazier, in the torcular Herophili in two minutes and in the urine in five, while it requires almost twelve hours for the stained fluid to reach the cervical lymph nodes. These findings are corroborated by the observations of Dandy and Blackfan.

The principal question at issue in regard to the absorption of cerebrospinal fluid under normal conditions is, therefore, not as to how the fluid escapes from the subarachnoid space, but rather as to the channels by which it reaches the venous circulation, and as to whether absorption is restricted to a certain area or whether it is a diffuse process limited only by the extent of the subarachnoid space.

At this writing it is difficult to decide whether we should consider

absorption a process of filtration *via* the arachnoidal villi, the precursors of the pacchionian bodies, into the dural sinuses, or whether we should look upon it as a process of diffusion into the capillaries of the subarachnoid space. It may be by one, or it may be by both of these processes.

It was maintained by Key and Retzius, in their monograph in 1876, that the fluid made its escape *via* the pacchionian bodies into the venous sinuses—a theory which was supported for some time. Inasmuch as the pacchionian bodies are not present in the young or in some of the lower animals, this hypothesis is not tenable. Weed has come to the conclusion that "the chief method of return of cerebrospinal fluid to the general circulation is by a process of filtration through the arachnoid villi into the great sinuses." Weed's experiments were carried on by means of an injection of a true solution of potassium ferrocyanid and iron ammonium citrate into the subarachnoid spaces during life, with subsequent precipitation of Prussian blue wherever the fluid penetrates in the head and neck by fixation of the tissues *in situ*. He found by this method that the fluid passed from the cranial subarachnoid space by way of the arachnoidal villi into the great sinuses, and according to his observations "absorption from the cranial subarachnoid space is much more rapid and much greater in amount than from the spinal portion."

On the other hand, if one grant Mott's canalicular theory that the cerebrospinal fluid is the medium of exchange between the nerve cells and the blood, then one must look upon capillary absorption as the true method of escape of the cerebrospinal fluid. As we have already seen, Mott postulated that through a process of diffusion and osmosis water and carbon dioxid passed from the cerebrospinal fluid in the perivascular spaces into the capillaries, and that by the same process salts and sugar passed from the blood to the fluid. Dandy and Blackfan, as the result of their recent experiments, have come to the conclusion that absorption is a diffuse process from the entire subarachnoid space directly into the capillary network. After isolating the cerebral subarachnoid spaces from the spinal they have found that there is "a quantitative absorption proportionately as great as from the entire subarachnoid space." It is difficult at this time to draw definite conclusions as to the relative merits of these theories, and before the problem of absorption can be finally settled we must await the results of further studies in the physiological laboratory and the clinic.

Amount of Cerebrospinal Fluid.—In regard to the total amount of cerebrospinal fluid in adults, the findings of various observers are not in accord, as shown in the following table by Holtzman:

Cotuguo	120-150	c.c.
Magendie	62	"
Testert	100-150	"
Luschka	75	"
R. Wagner	82	"

After death the cerebrospinal fluid is rapidly absorbed; after seventy-two hours none may be found at autopsy (Mestrezat). As shown in the above table, the total amount of fluid under normal conditions ranges from 60–150 cubic centimeters. Approximately half the total quantity of fluid is in the spinal portion of the subarachnoid space; the ventricles contain about 20–30 cubic centimeters.

Circulation of the Cerebrospinal Fluid.—The circulation of the cerebrospinal fluid is very slow. Cavazzani and Hill have shown that substances injected into the subarachnoid space require from 20 minutes to 2 hours to be generally distributed. The direction of circulation appears to be from the ventricles outward and downward; an active circulation toward the ventricles has not been demonstrated, although substances injected intraspinally may become widely diffused in the subarachnoid space. Blackfan and Dandy showed that, after intraspinal injections of finely divided carbon, there was rapid distribution of the particles throughout the subarachnoid space. They showed also that phenolsulphonphthalein injected intraspinally was demonstrable in the fluid obtained a few minutes later from the ventricles; these observations have an important bearing upon the distribution of serum injected intraspinally. The slowness of the circulation of the cerebrospinal fluid probably accounts in part for the different constitution of the ventricular and spinal fluids, and even of the spinal fluid at different levels, as shown recently by Solomon and Welles with the goldsol reaction, and also by the observations of Schmorl, who found in paresis that the ventricular fluid gave a positive Phase I globulin reaction, while the spinal fluid showed no increase above normal. The researches of Claude Bernard, Capelletti and Verneuil, Mathieu, Niccioli, and others tend to show that the cerebrospinal fluid is renewed six to seven times in 24 hours under normal conditions; when the fluid has been drawn off renewal is ordinarily very prompt and probably complete within half an hour.

Analogy of Cerebrospinal and Ocular Fluids.—The cerebrospinal fluid bears a very close physical and chemical resemblance to the perilymph of the internal ear and the aqueous humor of the eye. As emphasized by Wegefarth and Weed, both the cerebrospinal fluid and aqueous humor are elaborated by similar glandular structures, both are retained within similar cavities, both serve very similar functions, and both return ultimately to the major circulation through absorption by similar villous invaginations into the great sinuses of sclera and dura.

PHYSIOLOGY OF THE CEREBROSPINAL FLUID

Secretion of the Cerebrospinal Fluid.—Both clinically and experimentally it is known that cerebrospinal fluid is being constantly secreted

and is constantly escaping, but we are still in the dark as to the rate of secretion under normal conditions. The experiments of Frazier and Peet have shown that the normal rate of secretion may vary widely, even under normal conditions. They found, moreover, that the rate of secretion was practically uninfluenced by such grave circulatory disturbances as complete closure of both common carotid arteries. Therefore, they feel that ligation of the common carotid arteries for the relief of hydrocephalus has not a scientific basis.

In an attempt to find some substances which would have an inhibitory effect upon the secretion of the choroid plexus, Frazier has recently carried on a most interesting series of experiments. He felt that the only way to combat these excessive accumulations of fluid due to hypersecretion of the choroid plexus was to attack the problem at its source and find a substance which would inhibit its glandular activity. He tried the effect of extracts of the spleen, kidney, pancreas, testes, ovary, liver and adrenals, as well as such substances as urine, bile, cerebrospinal fluid, chloroform, ether, amyl nitrate, magnesium sulphate, and physiological salt solution, and found that the apparent increased rate after the injection of these substances was the result of a mechanical rather than a secretory process, to be attributed to the fall in arterial blood pressure; the latter increases the pressure in the cranial venous sinuses, thus forcing out the preformed fluid in the ventricles and cisterna magna. In his next series of experiments, Frazier found that brain extract caused an actual increase in the cerebrospinal fluid, wholly independent of the amount of fall in blood pressure. Dixon and Halliburton have found this to be true, not only of brain extract, but more particularly of choroid extract, and upon the basis of these findings have elaborated their hormone theory. In continuing his researches further, Frazier found that thyroid extract had a distinctly inhibitory effect upon the action of the choroid plexus quite independent of blood pressure changes. Frazier and Peet have also proved that diiodotyrosin, a synthetic product almost identical with that found in the thyroid, has the same inhibitory effect on the output of cerebrospinal fluid—although not to so marked a degree—as the thyroid tissue itself. While it is still too soon to forecast as to the significance of these findings, it seems that herein may lie an effective means of treating many cases of hydrocephalus heretofore unresponsive to treatment.

Dixon and Halliburton's experiments also show that there should be included among the substances which act as cerebral lymphagogues, an excess of carbon dioxid in the blood or drugs which interfere with respiration—such as pilocarpin and B-immazolylethylamin, dinitrobenzene and amyl nitrate—and the group of indifferent anesthetics and narcotics, which may act by interfering with oxygenation or by altering the physical conditions of secretion.

Functions of the Cerebrospinal Fluid.—While the cerebrospinal

fluid was for some time looked upon as ordinary lymph, it is now a well-known fact that there are no true lymphatics in either the brain or the spinal cord, the cerebrospinal fluid being quite different both chemically and physically from lymph and the contents of the other serous cavities.

It is obvious at first glance that the cerebrospinal fluid, passing from the ventricles to the subarachnoid spaces and filling up all the crevices not occupied by the nervous tissues and vessels, must have some very important physical functions. It is the cerebrospinal fluid which, acting as a water bed, protects the brain and spinal cord against shock and injury at every motion. It further serves to support the arteries and capillaries and to maintain a uniform pressure, and it is regarded by many as a delicate, self-adjusting mechanism by which pressure is equalized and distributed throughout the entire intracranial and intraspinal cavities during each systolic contraction, the intracranial pressure varying, as we shall see later, directly with the venous pressure. It is well known that in cases of atrophy of the brain, the cerebrospinal fluid fills up the dead spaces, thus maintaining the normal balance.

The amount and pressure of the cerebrospinal fluid are influenced by blood pressure and respiration and it serves as a delicate physiological regulator of intracranial volume and pressure. As the result of acute inflammatory changes in the meninges, with great increase in the volume of fluid this regulating mechanism is disturbed; in slower processes, as in tumors of the brain and cord, the fluid may serve for a time to equalize pressure. Important as these purely physical activities may be, the cerebrospinal fluid probably serves other and more important functions.

Protection against Infection.—The investigations of Goldmann, Frazier, Kafka and others suggest that the cerebrospinal fluid, together with the choroid plexus, plays the rôle of protector of the central nervous system against infection. To demonstrate that the choroid plexus is a barrier, Frazier and Peet injected 1 c.c. of a 1 per cent solution of trypan blue into the jugular vein of a rabbit, and though the plexus cells were stained, there was no disturbance of the central nervous system; the injection of 2 c.c. of a 1 per cent solution into the subarachnoid space was fatal in twelve hours. Goldmann's vital staining experiments further corroborate the theory that the choroid plexus is a "limiting membrane"; Kafka has found that in addition to withholding material from the nervous system, the cerebrospinal fluid creates certain "ferments" which protect the nerve cells against infection.

Metabolic Functions of the Cerebrospinal Fluid.—If, as we have been led to suppose, there are no true lymphatics in the brain and spinal cord, what is the ambient medium of exchange between the nerve cells and the blood? The researches of Mott, of Dixon and Halliburton, Goldmann, and others would seem to indicate that the cerebrospinal fluid plays an

important part in the metabolism of the central nervous system, conveying certain nutritive materials to the nerve cells and receiving from them the products of their metabolism. Mott, indeed, has suggested that the cerebrospinal fluid gives up water and carbon dioxid to the blood in exchange for oxygen and sugar, and Dixon and Halliburton believe that the cerebrospinal fluid is a means of eliminating carbon dioxid from the central nervous system. Certain it is that large quantities of carbon dioxid have been found in the cerebrospinal fluid, and when there is an excess in the blood it acts as a cerebral lymphagogue. The hypersecretion of cerebrospinal fluid following injection of brain extract, and more particularly of choroid extract, they attribute to the production of a specific chemical substance—a hormone which acts directly upon the secretory cells of the choroid plexus. For the present we can but conjecture as to the exact nature of this hormone, the product of brain metabolism. The fact that toxic material, the product of disordered metabolism and fermentation, has been found in the cerebrospinal fluid in meningitis by Kopetzky and others is a further proof that the waste products of cellular activity are eliminated through this medium.

Indeed, we are all agreed that there must be some means of exchange of products between the blood and the nerve cells. Since it has been demonstrated by the anatomical studies of Key and Retzius, the microscopical studies of Mott, and of Hill, and the staining experiments of Quincke and Jacob, Lewandowsky, Goldmann and others that the canalicular system, which is composed of the perivascular lymphatics, is continuous, on the one hand, with the pericellular and perineural spaces and, on the other, with the subarachnoid space, why should we not, for the time being at least, grant the cerebrospinal fluid, as it passes through the subarachnoid space and along the perivascular and pericellular spaces, to be the medium of exchange between the blood in the capillaries and the nerve cells?

Carrier of Internal Secretions.—The question has been raised as to whether the cerebrospinal fluid receives increments from the pituitary, thereby serving as a medium to bring the active principles of the secretion of the hypophysis into contact with the central nervous system. Cushing and Goetsch have demonstrated pituitrin, the secretion of the pars nervosa or intermedia, in the fluid withdrawn by lumbar puncture and found that injections of this fluid had the same effect as pituitrin itself. Cushing and Weed have recently found that extracts of the posterior lobe of the hypophysis increase the rate of production of the cerebrospinal fluid. This ability of the cerebrospinal fluid to bring the secretion of the hypophysis to the nerve cells would be one of its most important functions, if the hypophysis be as essential to metabolism as we are now inclined to believe.

The cerebrospinal fluid, therefore, though chemically and physically

very different from ordinary lymph, may have very similar functions in that it brings to the nerve cells the nutrient materials which they require, and carries away the waste products of their metabolism.

Normal Pressure.—While the problems associated with pressure of the cerebrospinal fluid need much further study before they will be finally elucidated, nevertheless, it has been proved conclusively that the pressure of the cerebrospinal fluid varies directly with the pressure of the venous sinuses and is practically identical with it. These findings are of extreme importance when considered in relation with the problems of absorption, and are a further proof of the correctness of the hypothesis that most of the fluid is taken up by the venous, rather than the lymphatic circulation.

The pressure of the cerebrospinal fluid oscillates under certain normal and abnormal conditions. There are slight variations caused by the effect of inspiration and expiration on venous pressure, but even these may be arrested by a slight increase of intracranial tension. Under normal conditions the pressure of the cerebrospinal fluid depends upon blood pressure, respiration and the total amount of fluid present. In the prone position respiration and pulsation of the heart (the transmissible blood pressure of Pfaundler) may alter the fluid pressure 10 to 30 mm. of water; coughing, crying, forced respiration, muscular movements and chilling of the trunk and extremities tend to increase the pressure. Abnormal conditions, such as closure of the carotid circulation, was found by Frazier to cause an immediate, though transitory, fall of cerebrospinal pressure. On the other hand, it has been proved, as would be expected, that obstruction of the venous circulation is followed by more or less constant increase in pressure. At the present time it is extremely difficult to draw any deductions from the variations in cerebrospinal pressure, partly because there is no standard instrument for measuring it, and partly because of the great variations in pressure even under normal conditions. The following is a list cited by Mestrezat, showing the great normal variations as given by various authors:

Cybierski	72- 90	mm.	of	water
Adamkiewicz	80-100	"	"	"
Key and Retzius	160-200	"	"	"
Bergmann	80-160	"	"	"
Quincke	40-130	"	"	"
Falkenheim	160-200	"	"	"
Schulzen	52-100	"	"	"
Krönig	125-150	"	"	"
Parisot	100-150	"	"	"
Boveri	170-200	"	"	"

Quincke, Parisot, Richet and Mestrezat regard as normal in the horizontal or prone position a pressure of 60-120 mm. of water (5-7.3 mm. mercury); 120-180 mm. indicate increased pressure and 200 mm. and over

a pathological increase. In the sitting position normal pressure may reach 200 mm. of water. In children the normal and pathological cerebrospinal pressure is about one-third less than in adults (Quincke).

I should like to call attention here to the manometer used by Frazier in his clinic at the University Hospital. It is a mercurial manometer (for full description, see Fig. 311) designed by his former assistant, Dr. L. H. Landon. If this instrument, or a similar one, were universally adopted and all observations recorded by it, it would be possible to draw conclusions and to interpret more clearly the variations from the normal. With the adult patient on the left side and quiet, the normal reading varies from 6 to 10 mm. of mercury, with an average nearer 8 mm.

Cerebrospinal Fluid Pressure in Disease.—Various pathological changes in the brain and spinal cord or general systemic disorders influencing the blood pressure may alter the pressure of the cerebrospinal fluid. A pressure of 300 mm. of water is not infrequently encountered; 500 mm. is to be considered high; 700 mm. is very high, while pressure reaching 1,000 mm. is quite rare. With Landon's instrument, readings even slightly above 12 mm., under proper attention to details of the technic, are regarded as suspicious, while readings of 20 mm. or higher are distinctly pathologic. Sudden and acute increase of cerebrospinal pressure is usually accompanied by clinical symptoms; chronic and slowly increasing pressure may not be accompanied by direct clinical evidences of the condition.

Among conditions leading to an *increased cerebrospinal pressure,* the following may be mentioned:

1. Hypersecretion of the fluid with normal or impaired absorption, resulting in an increased volume, as encountered in certain cases of internal and external hydrocephalus, congenital or acquired.

2. Increased volume of fluid as the result of serous and leukocytic exudation in acute meningitis of microbic origin.

3. Increased volume of fluid due to direct or reflex disturbances of vasomotor control and leading to acute congestion and edema of the meninges, as in the so-called "serous meningitis."

4. Effusion of blood in the ventricles or between the meninges or in the substance of the brain and cord.

5. Various other space-restricting lesions, such as tumors, fragments of bone and chronic inflammatory changes.

6. Syphilitic infection of the brain and spinal cord, especially in elderly persons with well-marked arteriosclerosis.

7. Certain of the acute intoxications, such as alcoholism and uremia, may be accompanied by increased pressure.

8. According to Ravaut, the administration of salvarsan may result in a temporary increase of pressure.

Increased pressure is found especially in meningitis, general paralysis,

cerebral and spinal tumors, epilepsy and hydrocephalus. In other affections of the central nervous system and in functional disorders the pressure is variable. Systematic studies in regard to *pathological decrease* in the cerebrospinal pressure have not been made thus far. A decrease in pressure may be expected in a proportion of persons who are greatly debilitated and have low blood pressure; likewise tumors so situated as to interfere with the flow of fluid from the ventricles into the spinal subarachnoid space may cause a marked decrease in the spinal pressure. The withdrawal of large quantities of fluid will, of course, result in a temporary lowering of the pressure, accompanied by such symptoms as headache and vertigo. As a general rule the pressure should not be lowered in this manner below 90-100 mm. of water.

PHYSICAL CHARACTERISTICS

The Normal Fluid.—The normal cerebrospinal fluid is limpid, colorless, sparkling and perfectly clear. When viewed in bulk a normal fluid may show a faint yellowish tint as compared with distilled water. Even when drawn immediately after a meal the fluid is clear and colorless. It is perfectly odorless and tasteless, although a slight salty taste may be apparent, due mainly to sodium chlorid. It does not coagulate spontaneously upon standing. The specific gravity is between 1.003 and 1.008; usually between 1.006 and 1.008. The freezing point (cryoscopy) is quite close to that of serum, 0.51° to 0.59° C. (Quincke, Widal, Sicard and Ravaut, Mestrezat, Mott and others). It varies greatly from day to day and in different individuals. According to Quincke, the freezing point may reach 0.75° C. The viscosity is somewhat higher than that of water, being from 1.000-1.105 (Datta, Galletta, Valensi). Investigations have shown that the electrical conductivity of cerebrospinal fluid bears a relation to the amount of soluble and formed elements it contains; the less it contains the lower the conductivity.

The Fluid in Disease.—A perfectly colorless and water-like fluid may be found in tuberculous meningitis and in the earliest stages of other forms, such as acute suppurative meningitis, as well as in various chronic lesions of the brain and spinal cord. Indeed it is customary to find a clear, watery fluid in most chronic affections of the brain and cord with the exception of pyogenic infections involving the meninges. Fluids may be opalescent, distinctly cloudy, purulent and even gelatinous, depending for the most part upon the presence of leukocytes, endothelial cells, bacteria and other inflammatory products.

The most frequent alteration of color is due to the presence of blood. A small vessel may be ruptured during lumbar puncture, so that several drops of blood may precede the flow of cerebrospinal fluid; for this reason

it is well to be provided with two or more receptacles, so that the first or blood-stained portion of fluid may be discarded. In some instances the blood resulting from accidental puncture may be mixed with the fluid so that it appears clear and water-like when dropping from the needle, but distinctly opalescent in bulk. When centrifuged, a small layer of red blood cells with clear supernatant fluid readily discloses the cause of the opalescence. A fluid that is first clear and then bloody indicates hemorrhage from the subarachnoid space, as in injuries of the skull and vertebral column. In cerebral hemorrhage or other hemorrhagic conditions where the blood is not in direct contact with the subarachnoid space, the hemoglobin may cause color changes while blood cells may be absent. At first the cerebrospinal fluid has a light yellow color; in a few weeks the color deepens to a brownish-yellow and gradually returns to the normal colorless fluid.

In severe icterus the cerebrospinal fluid may become discolored, but in practically all other instances a change in the color of the fluid is due to local conditions in the cerebrospinal system itself. The fluid collected from below spinal tumors and other space-constricting lesions may show a deep yellow color (xanthochromia) with spontaneous coagulation (massive coagulation), due to the presence of blood pigment and a great excess of protein constituents. Plaut, Rehm and Schottmüller report that the cerebrospinal fluid in a case of cholesteatoma was an emulsion of fat droplets and contained crystals of cholesterin.

The fluid in meningococcic meningitis frequently has a yellow or yellowish-green color; in pneumococcic meningitis the fluid may have a grayish color.

The *specific gravity* of the cerebrospinal fluid is increased when the fluid contains an excess of soluble protein, cells and bacteria, as in acute inflammatory involvement of the meninges.

The determination of the *freezing point* or *cryoscopy* of the cerebrospinal fluid has a limited value in examination and generally runs parallel with the freezing point of the blood serum. According to Widal, Sicard and Ravaut, Reichmann, Fuchs and others, the freezing point is lowered in tuberculous and other forms of chronic meningitis; it is increased in renal insufficiency (Widal and Froin, Javal), in diabetes (Loeper and Lawbry, Carrière, Reichmann) and in subarachnoid hemorrhage (Reichmann, Archard, Loeper and Lawbry).

Cerebrospinal fluids frequently develop *coagula and sediments,* which may be coarse, fibrillar or woolly in appearance. This tendency to coagulation is one of the earliest signs of meningeal inflammation and one of the last pathological changes to disappear. The fine cotton wool coagulum is especially characteristic of the fluid in tuberculous meningitis.

CHEMISTRY OF NORMAL CEREBROSPINAL FLUID

The *reaction* of the cerebrospinal fluid is weakly alkaline or neutral. It is generally regarded as possessing about one-half to one-third the alkalinity of the blood; according to Hurwitz and Tranter, however, the reaction as determined colorimetrically is more alkaline than the blood, the difference in the hydrogen-ion concentration of the dialysates of the two fluids being equal to 0.45. The slight alkalinity of the fluid is due to the presence of carbonates, bicarbonates and phosphates. According to Mestrezat, the alkalinity of normal fluid, as titrated with phenolphthalein, equals 1.25 to 1.30 grams of Na_2CO_3 per 1,000 c.c. fluid; the alkalinity of the ash, 1.40 to 1.43 per 1,000 c.c. fluid. According to Galletta, the reaction changes during the day are more alkaline in the morning than in the evening. As these occur quickly after the fluid is drawn, the reaction should be noted as soon as possible.

By far the major portion of cerebrospinal fluid is water; Zdarek has given the following analysis:

Water	989.54
Solids	10.45
Organic solids	2.09
Mineral ash	8.35
Albumins	0.76
Ethereal residue	0.35
Aqueous residue	8.22
Sulphuric acid (SO_3)	0.04
Chlorin	4.24
Carbon dioxid	0.49
Potassium oxid	0.16
Sodium oxid	4.29
Mineral ash, insoluble in water	0.16
Glucose	0.10

The quantities of soluble substances, both inorganic and organic, vary within wide limits; the average of the former is about 0.75 and the latter 0.22 per cent (Reichmann).

Inorganic Constituents

The mineral constituents of normal fluid are composed largely of chlorids and bicarbonates with traces of phosphates, sulphates and nitrates. The total, according to Mestrezat, equals 8.73 grams per 1,000 c.c. of fluid. Sodium chlorid constitutes the chief salt in cerebrospinal fluid, being present in 0.725 to 0.750 per cent. Traces of sodium and potassium salts are also present in the form of phosphates, carbonates

and bicarbonates; sulphates and nitrates only in traces. The potassium salts (.0054 Donath; .0043 Apelt and Schumm; .003 Mestrezat) and phosphates predominate and not the sodium salts as in the lymph. According to Blumenthal, the potassium salts constitute 20 to 30 per cent and the sodium salts about 15 per cent of the mineral matter. Mestrezat states that the following minerals are present, the amounts representing grams estimated in oxids per 1,000 c.c. of normal fluid: Na_2O, 4.346 gm.; K_2O, 0.251 gm.; CaO, 0.095 gm.; MgO, 0.050 gm.; Fe_2O_3, 0.002 gm.

Organic Constituents

Proteins

There is considerable discrepancy in the reports of various investigators regarding the identity of the protein found in normal cerebrospinal fluid. Thus, Landois regards the protein as serum albumin, Hammarsten as a mixture of globulin and albumose, Siemerling as globulin only, Halliburton as being principally a nucleoprotein, and Mestrezat as a globulin with traces of albumin and denies the presence of fibrinogen, albumoses, peptones, nucleo-albumins and mucin in normal fluids.

There is a need of further research in this subject, particularly with more delicate chemical methods and in coöperation with immunological reactions, as "salting out" tests have been shown by Osborne and his associates to be insufficient in separating the albumins from the globulins. Bearing in mind that the cerebrospinal fluid is probably the result of selective transudation or filtration from the serum of the blood stream in addition to a true secretion of the cells of the choroid plexus, it seems to me advisable to regard the protein of normal cerebrospinal fluid as a mixture of albumin and globulin, the latter predominating. At any rate the protein content of the cerebrospinal fluid is usually increased in organic diseases and injuries of the brain and spinal cord, and the detection of this increase is more important than exact quantitative differentiation of the various proteins.

The total protein content of normal cerebrospinal fluid according to various investigators is given as follows:

Quincke	0.2–0.5 per cent
Lenhartz	0.25 "
Pfaundler	0.2–0.4 "
Leri	0.5 "
Nonne and Apelt	0.5 "
Mott	0.3 "
Mestrezat	0.186 "
Nawratzki	0.22 "

Comba	0.19 per cent
Concetti	0.15–0.25 "
Marchand	0.06–0.20 "
Broden and Rodhain	0.25 "

In general, therefore, the total quantity of protein in normal cerebrospinal fluid may be taken as from 0.02 to 0.03 per cent or 0.2 to 0.3 grams per liter.

Delpech has stated the proportions of globulin and albumin in grams per 1,000 c.c. of fluid as follows:

Globulins	0.13
Albumins	0.04

According to most investigators, decomposition products of proteins, such as *albumoses, peptones, peptids, carbon dioxid and amino-acids* are absent from normal fluid. Sorensen and Ronchese have reported 0.010 grams of amino-acids per 1,000 c.c. of fluid; *ammonia* has been found in 0.0001 grams per 1,000 c.c. or, as usually reported, in traces; *nucleoalbumins* and *mucin* are generally regarded as absent from normal fluid.

Urea has usually not been found in normal fluid; Mestrezat reports 0.06 grams per 1,000 c.c. of fluid as within normal limits.

Cholin is not found in normal fluid; reports of various investigators upon the presence of traces are not acceptable in view of the faulty technic employed.

Methods of Protein Determination.—Owing principally to the work of Nonne and Apelt, whose famous "Phase I Reaction" is now well known, tests for protein excess in cerebrospinal fluid have proved of considerable value in the diagnosis of cerebral and spinal diseases, particularly those of syphilitic origin. The earlier tests aimed to measure the total protein content; later most attention has been given the globulins (fibringlobulin, euglobulin, and pseudoglobulin). For practical and clinical purposes, the so-called "globulin tests" are satisfactory for determining qualitatively the protein content of the cerebrospinal fluid; it is important, however, to know and bear in mind the normal limits and reactions in interpreting the results of any test for the purposes of diagnosis. The tests which I shall describe here are recommended on account of their simplicity and ease of manipulation. They are essentially qualitative and, while suitable for practical work, are not satisfactory for the more delicate and exact quantitative determinations required in chemical analyses and research.

General Directions.

A. The fluid to be tested should be free of blood. For this purpose fluid should be collected in two centrifuge or test tubes and the first flow discarded if blood-tinged; otherwise the fluid may be centrifuged to remove corpuscles. If more than traces of blood be present, the protein

reactions will be unreliable on account of the presence of serum proteins.

B. The fluid should be tested soon after withdrawal, particularly if collected in non-sterilized tubes, before well-marked bacterial multiplication has taken place.

C. These tests should be conducted in small thin-walled test tubes.

I. Method of Mestrezat (*Total Protein*).—To 2 c.c. of cerebrospinal fluid add 6 drops of 33 1/3 per cent solution of trichloracetic acid and heat to boiling. A faint opalescence is normal; well-marked opalescence, turbidity and precipitate indicate an increase of protein. By centrifugalization the precipitated protein may be roughly gauged.

In a given case I have found this method of value as a rough quantitative measure of the total protein from day to day and capable of indicating an increase or decrease of protein.

II. Method of Nonne and Apelt (*Phase I Globulin Reaction*).—This well-known test is conducted as follows:

(1) In a small test tube place 1 c.c. of cerebrospinal fluid and 1 c.c. of a saturated solution of ammonium sulphate (prepared by placing 85 grams of Merck's purified and neutral ammonium sulphate and 100 c.c. distilled water in an Erlenmeyer flask and heating to boiling until no more of the salt will go into solution; then, cooling slowly, filter through paper to remove the excess of salt).

(2) Mix well and stand aside for 3 minutes; compare with another tube containing cerebrospinal fluid only.

(3) A normal fluid remains clear or shows but a very faint opalescence; an increase of protein is indicated by opalescence, marked opalescence, turbidity or visible precipitation.

The Phase II reaction is conducted by filtering the mixture of cerebrospinal fluid and ammonium sulphate, acidulating and boiling. It is supposed to show the albumin content, but possesses little or no practical value.

Nonne and Apelt originally used 2 c.c. of fluid; Zaloziecki used 0.5 c.c.; in conducting the test 0.5 to 2.0 c.c. of fluid may be used, depending upon the quantity available.

III. Method of Ross-Jones (*Globulins*).—This simple modification of Nonne-Apelt's Phase I Reaction consists merely in layering 1 c.c. of spinal fluid over 2 c.c. of saturated solution of ammonium sulphate prepared as described above. When a white ring is obtained after three minutes, the reaction is considered to signify a globulin excess.

IV. Method of Noguchi (*Globulins*).—This valuable and simple method has gained a wide popularity:

(1) In a small test tube place 0.2 c.c. of cerebrospinal fluid and add

1 c.c. of a 10 per cent solution of butyric acid in normal salt solution.

(2) Heat to a brief boiling.

(3) Add 0.2 c.c. of a normal solution of sodium hydroxid and boil once more for a few seconds.

The normal reaction is clear or shows a faint opalescence which does not settle out for several hours; a positive reaction is indicated by marked

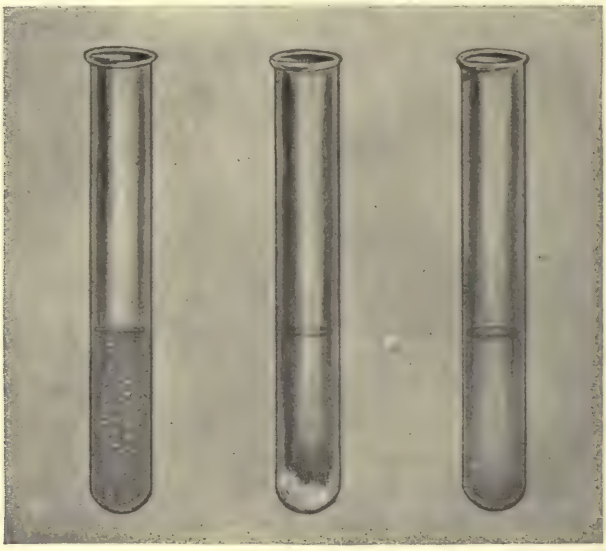

FIG. 82.—THE NOGUCHI BUTYRIC ACID TEST FOR GLOBULINS.

The tube on the extreme left shows the formation of flocculi within a few minutes after adding NaOH; the middle tube shows a strongly positive reaction after standing several hours (supernatant fluid quite clear); the tube on the extreme right shows a very slight opalescence, but no flocculi (within the limits of normal).

opalescence, turbidity or visible granular precipitate, which settles in about an hour under a clear supernatant fluid (Fig. 82).

V. METHOD OF PANDY (*Globulins*).—This very simple and decisive test is worthy of more extensive use:

(1) To 1 c.c. of a saturated watery solution of carbolic acid (1 part carbolic acid crystals and 15 parts distilled water) in a small test tube is added 1 drop of clear cerebrospinal fluid.

(2) The immediate formation of a bluish-white ring or cloud is the evidence of an abnormal protein content; a white precipitate indicates a strong reaction; finer reactions are detected over a dark surface.

Zaloziecki prepares the reagent by diluting 80 to 100 c.c. of acidum carbolicum liquefactum purissimum with distilled water up to 1,000 c.c. The mixture is well shaken and placed in an incubator for several hours. After complete clarification at room temperature, which requires several

days, the clear supernatant fluid is removed and used as the reagent. It should be kept at room temperature and well stoppered to prevent evaporation. Pandy's test is very delicate and seldom yields equivocal or misleading results.

VI. Method of Kaplan (*Globulins*).—This is also a delicate and useful technic; I employ the test as a rough quantitative method:

(1) Into 5 test tubes (1 x 8 cm.) place 0.1, 0.2, 0.3, 0.4 and 0.5 c.c.

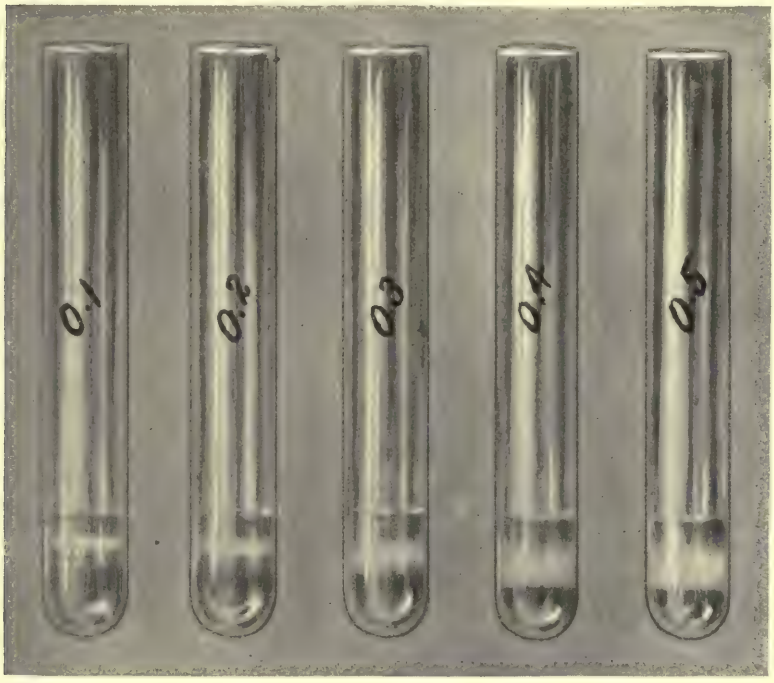

Fig. 83.—The Kaplan Protein Test.

of cerebrospinal fluid respectively; to each in turn add distilled water until brought up to 0.5 c.c.

(2) Heat each tube until it boils up twice.

(3) Add to each tube 3 drops of a 5 per cent solution of butyric acid in normal salt solution and carefully and slowly underlay the contents with 0.5 c.c. of a saturated solution of ammonium sulphate prepared as described under the Nonne-Apelt method.

(4) Set the tubes aside for 20 minutes and read the results.

Normal fluids yield an opalescent reaction, but not a distinct ring; in this test if 0.1 c.c. of fluid yields a distinct ring it is recorded as a 0.1 c.c. excess and so on to 0.5 c.c. (Fig. 83).

Of these various qualitative methods, I use routinely those of Noguchi,

Pandy and Kaplan. In recording the results, the following scheme has proved useful:

— = negative reaction (perfectly clear or very faint opalescence).
± = doubtfully positive (well-marked opalescence).
+ = weakly positive (cloudy).
++ = strongly positive (marked turbidity or granular precipitate).

In addition to these tests others have been recommended: Guillan and Parant, in their test, add to the fluid an equal volume of a saturated solution of magnesium sulphate, filter and boil the filtrate; Nissl overlays a saturated solution of ammonium sulphate with clear fluid; Cimbal precipitates with a solution of zinc sulphate (Fraction I), filters and boils the filtrate (Fraction 2); Gordon adds 1 drop of a 1 per cent watery solution of mercuric chlorid to 1 c.c. of clear fluid, opalescence and turbidity indicating a positive reaction.

Potassium Permanganate Reduction by Organic Substances.—Mayerhofer has found that normal cerebrospinal fluid would reduce potassium permanganate when boiled in a strongly acid medium. The amount of decinormal permanganate solution, which boiled for ten minutes in a strongly acid medium is reduced by 1 c.c. of cerebrospinal fluid, he called the "permanganate reduction index." This amount was usually between 2 and 2.3 c.c. in normal fluids. Pathological fluids containing a higher content of organic substances were found to reduce a larger quantity of permanganate solution and an attempt has been made to place the test on a practical basis, particularly in the diagnosis of tuberculous meningitis.

The titrations should be done as soon as possible after withdrawal of the fluid. Boveri has reported favorably upon the diagnostic value of this test in tuberculous meningitis, while Simon reported rather unfavorably. Hoffman and Schwartz believe the test possesses distinct value in the examination of cerebrospinal fluid and have classified the reduction indices as follows: (1) low indices, below 2; (2) borderline indices, between 2 and 2.5; (3) high indices, above 2.5. Further mention of permanganate reduction will be made later in the discussion of the pathological chemistry of cerebrospinal fluid. In my experience this test has not yielded information of more practical value than that obtained with the protein tests.

Technic.—Before the main test is conducted it is necessary to determine by titration how much N/10 solution of oxalic acid is necessary for the reduction of 10 c.c. of N/10 potassium permanganate solution in the presence of sulphuric acid, as follows: In a chemically clean beaker place 50 c.c. of distilled water, 10 c.c. of dilute sulphuric acid (1 part

concentrated sulphuric acid and 3 parts of distilled water) and 10 c.c. of N/10 solution of potassium permanganate. Boil gently for ten minutes and maintain slow boiling while N/10 solution of oxalic acid is added from a buret until all color has disappeared. The amount of oxalic acid required to reduce all of the potassium permanganate is determined; this amount is likely to vary from time to time.

The main test is then conducted as follows: In a chemically clean beaker place 1 c.c. of cerebrospinal fluid (as soon after collection as possible), 50 c.c. of distilled water and 10 c.c. of diluted sulphuric acid. Heat to boiling and maintain gentle boiling. Add 10 c.c. of N/10 solution of potassium permanganate and boil gently for ten minutes. Slowly add the proper amount of N/10 solution of oxalic acid as determined above. The fluid should now become colorless, indicating that the permanganate solution has been reduced. Add from a buret N/10 solution of potassium permanganate until the first appearance of a faint rose color. The amount of permanganate solution required in cubic centimeters is the "reduction index" of the fluid under examination.

Carbohydrates (*Dextrose*)

Normal cerebrospinal fluid contains a substance capable of reducing copper in alkaline solution, first described by Deschamp and Bussy in 1852. This reducing substance has been studied by a number of investigators using Fehling's, Williamson's, Trommer's, phenylhydrazin, fermentation and other tests and various substances, notably dextrose and pyrocatechin, regarded as reducing agents. Quincke originally regarded this substance as dextrin, while Nawratski in 1897 and Deniges in 1898 claimed that it was principally dextrose. Since that time many have confirmed the presence of a reducing substance in cerebrospinal fluid which undergoes fluctuations in disease and particularly in acute suppurative meningitis. *Recent researches, particularly by Nawratzki, Deniges and Mott, have shown quite conclusively that the reducing substance of normal fluid is dextrose;* I believe that Halliburton himself, who originally held that pyrocatechin was the reducing agent, has given up this belief in favor of dextrose. Mestrezat also believes that dextrose forms almost all of the reducing substances of normal fluid, but in pathological conditions other reducing agents may be present by reason of the multiplicity of reducing substances in the blood, of the abundance of galactosids in the brain and of the glycogen of leukocytes and other cells.

A few investigators have made quantitative analyses over a limited number of cases, the results of which are variable as may be expected with the use of various methods. The results are as follows:

Von Jaksch	0.06–0.08	per cent
Mestrezat	0.0534	"
Nawratzki	0.046	"
Kopetzky	0.046	"
Hopkins	0.06–0.075	"

In general the physiological limits of glucose in cerebrospinal fluid may be placed from 0.048 to 0.058 per cent (Mestrezat) or 0.48 to 0.58 grams per 1,000 c.c. The quantity of dextrose in normal cerebrospinal fluid is slightly less than that in the blood; Hopkins, using Bang's micromethod, found that the blood sugar averages about 10 mgm. per 100 c.c. higher than that of the fluid. Hammarsten and Abderhalden have also found the blood sugar slightly higher.

Carbohydrate Tests.—Tests for the reducing power of cerebrospinal fluid should be conducted with fresh fluid and as soon after withdrawal as possible.

Fehling's Reagent.—To 1 c.c. each of the copper and alkaline solutions add 10 c.c. of water and heat to the boiling point. If the color remains unchanged, the reagent is fit for use. In a small thin-walled test tube heat to the boiling point equal quantities of reagent and fluid. Reduction is indicated by a change of color and the development of the red precipitate of cupric oxid. Holzman adds 2 drops of equal parts of Fehling's alkaline and copper solutions to 2 c.c. of spinal fluid and heats to boiling. The disadvantage of Fehling's test is that it may be masked by an excess of protein.

Bang's Micromethod.—Hopkins has reported quite favorably upon the value of this method, particularly as a quantitative test. Only three or four drops of fluid are needed and the protein content of the fluid is thoroughly separated before the reduction of copper takes place. Hopkins and Strode have also found Benedict's new colorimetric method to yield fairly good and constant results.

Other Organic Constituents

According to Mestrezat the *total nitrogen* of normal cerebrospinal fluid is 0.197 gm. per 1,000 c.c. Deniges and Sabrazes found *urea* in the fluid in cases of uremia, which findings have been confirmed by many observers. According to Mestrezat, urea (0.06 gm. per liter) and traces of free ammonia may be found in normal fluid. Mott has reported upon the presence of traces of *cholin* in normal fluid, but this Mestrezat and others deny. *Lecithin* may be present in traces (0.02 gm. per liter, Mestrezat); but the presence of *cholesterin* under normal conditions is disputed. *Lactic acid* is found in traces (0.3 gm. per 1,000 c.c. according to Mestrezat);

acetone and *oxybutyric* and other organic acids are regarded as absent from normal fluid.

CHEMISTRY OF CEREBROSPINAL FLUID IN DISEASE

Owing to the difficulty of securing large amounts of cerebrospinal fluid by lumbar puncture, practical chemical methods are usually confined to examinations for protein, reduction tests, and chlorid determinations. Investigations bearing on the mineral constituents, organic acids and fatty substances have been made with interesting and instructive results, but they demonstrate little of practical value owing chiefly to difficulties in technic and insufficient amounts of suitable fluid.

As previously stated, changes including alterations in reaction occur soon after removal of fluid. According to Coriat the fluid tends to become acid after death. In acute inflammation of the meninges of various types the reaction of the fluid due to carbonates remains unchanged (Mestrezat) or may be decreased by the formation of lactic acid. Likewise, in acute and chronic meningitis, meningomyelitis and other conditions, the alkalinity due to the substances that constitute the ash of the fluid is variable and further researches are required in each disease to show the origin and nature of the minerals causing alteration in reaction.

Inorganic Constituents

In general the total of mineral constituents is somewhat decreased in tuberculous meningitis, averaging about 7.61 grams per 1,000 c.c. of fluid as compared with the normal of 8.73 grams. Deniges and Sabrazes and Mestrezat have not found these low figures in meningococcic, pneumococcic or streptococcic infections and regard a low total mineral content as somewhat characteristic of tuberculous meningitis. An increase of total mineral matter has been found in renal insufficiency, the figures varying from 9.40 to 13.30 grams per 1,000 c.c. of fluid.

Chlorids.—In acute inflammation of the cerebral and spinal meninges, the *chlorid* content of the fluid is reduced. Slight reduction (0.7 per cent) is found in cerebral congestion and edema; marked reduction (0.64 to 0.6 per cent) is found in acute meningitis. In tuberculous meningitis the chlorids may sink to 0.5 to 0.6 per cent. In subacute and chronic meningitis the reduction is much less. An estimation of the chlorids, therefore, possesses value in differentiating between infections accompanied by cerebral congestion or true meningitis, also between myelitis and meningomyelitis, encephalitis and meningo-encephalitis. An increase of chlorid content is found in renal insufficiency.

The following table modified after Mestrezat, summarizes the relation of chlorids to cerebrospinal fluid in disease:

Decrease in Chlorids (Below 0.71 per cent)	Serous Edema (Slight decrease)	Tuberculous Meningitis 0.5-0.61 per cent
	Purulent Meningitis (Marked decrease)	Acute Suppurative Meningitis 0.64 per cent
	Chronic Meningitis (Slight decrease)	
Increase in Chlorids (0.75 per cent and higher)	Renal Insufficiency	
Normal Chlorids (0.732 per cent)	Myelitis and Encephalitis (When meninges are not involved)	
	Sclerosis, Psychoses (Non-organic)	
	Renal Insufficiency with Meningitis (Conditions may be balanced)	

For the quantitative estimation of sodium chlorid at least 10 c.c. of cerebrospinal fluid are required; the method of McLean and Van Slyke and Foster's modification of their method, have proven quite reliable.

Phosphates.—The normal phosphate content is regarded as about 0.003 per cent; this percentage is in those diseases accompanied by degenerative processes of the cerebral and spinal substances. The researches of Donath, Nonne and Apelt, Forbes and others have shown that comparatively wide variations occur in diseased conditions and that a qualitative analysis of fluids for phosphates possesses little or no diagnostic value. For example, Apelt and Schumm found in epilepsy 0.0016 to 0.0039 per cent, in general paralysis 0.0056 to 0.0074 per cent, in uremia 0.0091 per cent and in delirium tremens 0.0053 per cent. After death the percentage of phosphates is considerably increased.

Sulphates and Carbonates.—Quantitative studies of the sulphates and the carbonates of sodium and potassium have not yielded either constant or practical results.

Organic Constituents

Protein

The examination of the cerebrospinal fluid for its protein content has proved of great value in the diagnosis of cerebrospinal diseases. The earlier investigations in this field were mainly concerned with quantitative estimation of the total protein of the fluid; within recent years more attention has been given to qualitative tests, particularly of the globulins, mainly as a result of the prominence given this subject by Nonne and his co-workers, whose famous Phase I Reaction has succeeded in establishing the practical value of qualitative protein tests in the diagnosis of certain diseases of the central nervous system.

As I have previously mentioned in discussing the proteins of normal fluid, considerable differences in opinion exist regarding the identity of the protein in normal fluid. The same applies to some extent to the fluid in disease. Investigators generally agree, however, that both serum *albumin and globulins* are present in the fluid in most diseases accompanied by a total increase of protein, particularly in the acute meningitides, and in certain syphilitic diseases, notably cerebrospinal syphilis and the so-called metasyphilitic diseases, such as paresis and tabes dorsalis. In these the globulin increase appears to be more prominent.

Qualitative differentiation of the proteins in cerebrospinal fluid have been largely based upon "salting out" methods, such as saturation with ammonium sulphate; as I have previously mentioned there is need of further study with more refined methods before absolute statements can be made on the quantitative proportions of the albumin and globulin content of the fluid in health and disease. On the basis of the work already done with present methods it would appear that in certain diseases the increased total protein of the fluid may be due to an increase of serum albumin alone with a normal quotient of globulins; or the increase may be due largely to the globulins without material increase of the albumins.

In disease, and particularly in those conditions marked by a stasis of the fluid, the products of protein hydrolysis or decomposition, as the albumoses, peptones, peptids, ammonia and amino-acids may be found; likewise in certain diseases accompanied especially by a considerable increase of cells, the conjugated proteins as nucleoprotein are to be found. I shall refer later to these protein products in more detail.

Quantitative Consideration of Protein Content.—The proteins of the fluid in diseases of the cerebrospinal system may be: (*a*) increased, (*b*) normal, or (*c*) decreased.

An *increase* of the proteins is found in (1) acute and chronic inflammatory diseases of the cerebral and spinal meninges; (2) in hemorrhagic conditions due principally to injuries of the meninges; and (3) in conditions accompanied by a great increase of cells, the increase of protein being largely ascribed to disintegration of leukocytes (cytolytic). Mestrezat also mentions (4) a residual type of protein increase, found after the subsidence of recent and acute inflammation of the meninges. A well-marked increase of the protein in the fluid is always pathological and usually indicates an inflammation of either infectious or toxic origin, involving the meninges, plexuses or substance of the brain or cord, or accompanied by congestion, infiltration and exudation of serum and cells. In all instances an acute inflammation shows a greater protein increase than chronic inflammation. The following examples giving the total protein calculated in grams per 1,000 c.c. of fluid serve to illustrate the range of protein

increase in disease (0.2 to 0.3 grams of protein per 1,000 c.c. fluid being taken as normal):

Massive coagulation and xanthochromia	6–28	grams
Epidemic cerebrospinal meningitis	3–9	"
Pneumococcic meningitis	3–11	"
Streptococcic and B. coli meningitis	0.5–2	"
Tuberculous meningitis (infants)	1–2	"
" " (adults)	2–3	"
Cerebrospinal syphilis	0.35–1.2	"
Tabes dorsalis	0.5–1.5	"
Paresis	0.3–2.2	"

A *normal* protein content of the fluid may be found in the following diseases involving the nervous system and, therefore, does not in itself indicate a normal condition of the central nervous system: (1) in certain affections of the central nervous system, such as multiple sclerosis, brain tumor and epilepsy; (2) in involvement of the peripheral nerves, such as neuritis and polyneuritis; (3) in non-organic psychoses; and (4) in general infections, such as typhoid fever and pneumonia with meningeal irritation, but without actual involvement of the meninges.

A *decrease* in the protein may be regarded as present when less than 0.1 grams of protein per 1,000 c.c. of fluid is found. This may be observed in hypersecretion of the choroid plexus as the result of toxic stimulation, also in arteriosclerosis, involving the meningeal vessels with hypertension and increased transudation or filtration of spinal fluid.

Clinical Significance of Protein Determination.—In so far as the qualitative tests for protein are concerned, their simplicity, the ease with which they are conducted and the small amount of fluid required, render them of particular value to clinicians in the diagnosis and prognosis of cerebrospinal diseases. The results of these tests, however, can seldom be interpreted on their own merits alone, but in conjunction with other examinations, such as cell counts, reduction tests for dextrose, chlorid determination and the Wassermann reaction. While an increase of protein indicates organic and pathological changes, the absence of protein increase does not exclude organic changes and possesses no absolute value; indeed, as pointed out above, certain conditions may be accompanied by an actual decrease in protein.

Protein Tests.—Qualitative tests and particularly the "globulin" tests usually serve the purpose of detecting a normal or increased protein content of the fluid. Small amounts of fluid will suffice for these tests, the Pandy test requiring 1 drop, the Noguchi test 0.2 c.c. and the Nonne Phase I test 0.5 to 1.0 c.c. The clinical quantitative test of Kaplan is serviceable for the globulins and that of Mestrezat for the total protein. The technic of these and additional tests are described on pages 156-160.

Reduction of Potassium Permanganate by Organic Substances.—Mayerhofer claims that the permanganate reduction index possesses value in the diagnosis of meningitis, particularly tuberculous meningitis. Hoffman and Schwartz have reported that while the test is not specific, indices usually fall into certain groups, eliminating or suggesting certain diseases. In their series, a reduction index of over 2.5 in a clear fluid almost invariably indicated the presence of an actual inflammatory process of the meninges, usually of tuberculous origin. High indices were also found in the fluids of encephalitis, serous meningitis and poliomyelitis.

Of particular interest are the results in serous meningitis. Mayerhofer claims that the test is negative in this condition and strongly positive in tuberculous meningitis, thereby offering an additional aid in diagnosis. Simon was unable to corroborate these claims, his readings varying from 2.1 to 2.8. Hoffman and Schwartz found their readings in a group of cases to range from very low to moderately high. It would appear that the Mayerhofer test is worthy of further study, but absolute statements regarding its value in the examination of cerebrospinal fluid cannot be made at the present time; in my opinion the information it yields is of no greater value than that gained by the simpler protein tests.

Fibrinogen and Fibrin.—Several hours after the withdrawal of cerebrospinal fluid in acute and some types of chronic meningitis the formation of a fibrin clot or coagulum may be observed. In tuberculous meningitis, for example, the fluid may be water clear and physically resemble normal fluid; the formation of a fibrin coagulum, however, denotes a pathological condition and aids in the proper diagnosis and interpretation of this infection. More extensive and complete coagulation, however, is found with loculated or enclosed fluids removed from below tumors of the spinal cord. The fluid has a deep yellow color and undergoes early and frequently complete coagulation. These changes known as the syndrome of *massive coagulation and xanthochromia* or the syndrome of Froin (*vide* page 184) are characteristic of spinal fluids that have been loculated or enclosed in a cavity and particularly in space constriction of spinal cord tumors. The fibrin ferment is regarded as being derived from leukocytes; in acute inflammation of the meninges the amount of ferment is probably increased as the result of the increased numbers of those cells in the fluid.

Conjugated Proteins.—Nucleoproteins or compounds of one or more protein molecules with nucleic acid and mucins or glycoproteins, both of which are precipitable by acetic acid, may be present in the cerebrospinal fluid in disease. The presence of mucin in the fluid from cases of tuberculous meningitis, congenital hydrocephalus, tabes dorsalis and cerebral tumors has frequently been noted. Nucleoprotein has been found in the fluid of cases of general paralysis and tabes dorsalis.

Albumoses and Peptones.—As previously stated, products of protein hydrolysis, such as albumoses, peptones, polypeptids and amino-acids, are not found in normal cerebrospinal fluid. Where there is an increased amount of fluid with protein excess accompanied by stasis, these products of decomposition may be found in massive coagulation and xanthochromia, in tuberculous and epidemic cerebrospinal meningitis, as well as in hydrocephalus in small quantities. Traces have also been found in other space-constricting processes, such as sarcoma and Pott's disease of the spine.

Amino-acids.—Normally the minutest traces of amino-acids may be detected in some fluids: about 0.004 grams per 1,000 c.c. of fluid. In acute meningitis and space-constricting processes, such as tumors and chronic inflammatory conditions, protein disintegration may continue to the formation of amino-acids, reaching in some instances as much as 0.044 grams per 1,000 c.c. of fluid.

Ammonia.—Many of the investigations bearing upon the presence of ammonia in the cerebrospinal fluid have been conducted with Nessler's reagent but with conflicting results. Traces have been found in the fluid from cases of tuberculous and influenzal meningitis, general paralysis and tumors of the spinal cord with massive coagulation and xanthochromia. On the other hand, Deniges and Sabrazes, de Buck and others have reported negative findings in tuberculous meningitis, epilepsy, hydrocephalus and chronic nephritis with edema.

Urea.—According to Mestrezat, the presence of more than 0.25 grams of urea per 1,000 c.c. of fluid denotes a pathological condition; 3.0 grams in the same amount of fluid indicates fatal intoxication. From 0.1 to 0.51 grams per 1,000 c.c. of fluid have been found in tuberculous and epidemic cerebrospinal meningitis, from traces to 0.75 grams per 1,000 c.c. in hydrocephalus and from 0.41 to 0.6 grams per 1,000 c.c. in paresis.

Cholin.—Since Mott and Halliburton in 1889 reported cholin in the spinal fluid in organic diseases of the central nervous system accompanied by disintegrative changes, considerable research has been made in this field. Donath in 1903 and Deniges and Sabrazes in 1905 reported positive findings in tabes dorsalis, purulent meningitis, epilepsy and chronic myelitis, and others in some cases of paresis and acute meningitis. The accuracy of the method employed has been questioned so that the presence of cholin in cerebrospinal fluid should be left open for further investigation.

Carbohydrates and Derivatives

The reducing substance in cerebrospinal fluid, which is now generally accepted to be dextrose, may be decreased or increased in diseases of the brain and spinal cord.

Decrease in Carbohydrates.—A decrease in the quantity of dextrose (normal 0.048 to 0.058 per cent) has been reported in the following diseases:

Acute infectious meningitis of meningococcic, pneumococcic, staphylococcic and streptococcic origin. Probably the most marked decrease (0.035 per cent and less) occurs in this group of cerebrospinal diseases. In eight cases of suppurative meningitis Hopkins, using the micromethod of Bang, found the reducing substance present in from 0.015 to 0.079 per cent and, therefore, in most instances below normal. In tuberculous meningitis there is also a decrease in the amount of reducing substances, Hopkins finding in 16 cases from 0.017 to 0.066 per cent; usually the greatest diminution is found in the fluids from suppurative meningitis of other origin. In the early stage of meningitis spoken of as "meningismus," particularly that due to pneumonia, typhoid fever, gastrointestinal disturbances and the like, the amount of reducing substance is unchanged.

In chronic meningitis and various affections of the nervous system, a decrease (0.035 to 0.048 per cent) of reducing substances may be found. In tabes dorsalis, paresis, cerebrospinal syphilis and hydrocephalus, low values are not unusual. Hopkins reports a decrease in 20 out of 29 cases of syphilis, the decrease being frequently so marked as to give values ranking next to meningitis. Mott has reported a decrease in reducing substances in dementia precox.

The cause of this reduction of dextrose in the cerebrospinal fluid in disease has been variously explained. In acute suppurative meningitis it is supposed that the bacteria consume the sugar as a food substance, and as recovery takes place with coincident decrease in the numbers of bacteria, dextrose gradually reappears in the fluid. Mestrezat also explains the decrease on the basis that the large numbers of cellular products of inflammation, red and white corpuscles, absorb a portion of the dextrose.

Increase of Carbohydrates.—The most marked increase in the percentage of dextrose occurs in diabetes mellitus, reaching as high as 0.105 to 0.66 per cent. In intoxications accompanying pneumonia, variola and typhoid fever an increase in dextrose may be noted (0.06 to 0.084 per cent, according to Mestrezat) and in uremia high values are quite common. In 14 cases studied by Hopkins, 7 gave high values, and in these the blood sugar was also found to be increased. In cerebral tumors an increase in dextrose (0.068 to 0.010 per cent) has been reported by Sicard and Rosseau-Langwelt, while Mestrezat has reported an increase (0.06-0.09 per cent) in amyotrophic lateral sclerosis, syringomyelia and anterior poliomyelitis. In epilepsy, Boyd found Fehling's test strongly positive in 4 cases, while Thabius and Karpar report negative results. Hopkins in a study of 14 cases found 7 with

a slight increase, the remainder yielding normal results. In diabetes mellitus the increase of dextrose in the fluid is to be ascribed to the high blood sugar content. As a general rule, an increase of dextrose in the cerebrospinal fluid is accompanied by hyperglycemia and glycosuria. In other conditions the increase of dextrose is ascribed to congestion of the meninges with passage of the dextrose from the blood to the fluid. In acute meningitis there is probably the same tendency to increase which is counterbalanced by active consumption of the dextrose by the invading bacteria.

Methods of Testing Carbohydrate Content.—These have been described in the section on Normal Cerebrospinal Fluid. It is to be emphasized that the examinations should be made as soon as possible after withdrawal of the fluid. Tests with Fehling's solution are crude, but fairly satisfactory, if a uniform technic be employed. Generally such tests show the presence or absence of dextrose without demonstrating finer quantitative differences unless a wide experience has been gained with a uniform technic. Whenever possible quantitative tests, such as the micromethod of Bang, should be used. To the practicing physician probably Fehling's test has its greatest value in the diagnosis of acute suppurative meningitis, especially that caused by the meningococcus when no reduction at all takes place. It is advisable for the physician to carry Fehling's solution in his bag, so that the test may be conducted at the bedside. In "meningismus" normal or almost normal reduction is the rule. In syphilis, hemorrhage, tumor and other conditions, the reduction test for dextrose may prove of value and should always be included in the routine examination of cerebrospinal fluid.

Acetone.—In diabetes mellitus, and particularly in diabetic coma, acetone and even diacetic and oxybutyric acids may be present in the cerebrospinal fluid, and should always be sought when the fluid sugar reaches 0.09 per cent. The methods of testing for this substance are similar to those used in urinalysis. From the standpoint of practical diagnosis it would appear that an examination for acetone possesses value in the differential diagnosis of diabetic coma from the coma of apoplexy, uremia and alcoholism. From the standpoint of prognosis the presence of acetone in the fluid is of very grave import and therapeutic measures, aiming to neutralize the diacetic and oxybutyric acids, which may be present in the fluid, may prolong the life of the patient.

Lipoids and Other Organic Substances

Lipoids.—Under the term *lipoids* are included all fatty substances soluble in ether and chloroform—principally lecithin, cholesterin, phosphatids and phosphorous-free cerebrosids.

Lecithin.—Traces of lecithin have been reported by several investigators as present in normal cerebrospinal fluid; Mestrezat has found 0.002 per cent. The chemistry of this substance, however, is so complicated and confusing and the methods for its detection and quantitative study so uncertain, that reports on its presence and increase in cerebrospinal fluid are unreliable. Donath has reported an increase in the fluid in tabes dorsalis and jacksonian apoplexy.

Cholesterin.—As previously mentioned, some investigators have reported traces of cholesterin in normal fluid; others have been unable to find any at all. Pighini, using Liebermann's cholesterol-reaction, has reported cholesterin present in the fluids of 24 out of 25 cases of paresis and 12 of 22 cases of epilepsy. Mott has reported positive findings in paresis and chronic dementias; others, traces of cholesterin in tabes and hydrocephalus and cholesterin crystals have been found in the spinal fluid in cases of cholesteatoma.

Hauptmann Saponin Reaction.—Hauptmann believes that inhibition of saponin hemolysis by the fluid from persons suffering with various cerebrospinal diseases is due to the presence of minute traces of cholesterin. Most marked inhibition of hemolysis has been observed in the fluids both from cases of brain and spinal cord tumors; the reaction may also be observed in tabes, cerebrospinal syphilis, multiple sclerosis and other conditions.

Technic.—Human erythrocytes are secured by removing 10 c.c. of blood by venous puncture and adding to 10 c.c. of a 2 per cent solution of sodium citrate in normal salt solution. The cells are washed three times with normal salt solution by centrifuging and after the last washing a 7.5 per cent suspension of the cells prepared.

A stock 5 per cent solution of Kahlbaum's saponin is prepared in distilled water. Saponin is readily soluble in water at 37.5° C. This solution should be left in a refrigerator and is good for about one month. From this stock solution a 1:10,000 solution is prepared with normal salt solution and titrated for hemolytic activity in a series of chemically clean test tubes as follows:

0.4	c.c.	of	1:10,000	solution	of	saponin
0.45	"	"	1:10,000	"	"	"
0.5	"	"	1:10,000	"	"	"
0.55	"	"	1:10,000	"	"	"
0.6	"	"	1:10,000	"	"	"
0.65	"	"	1:10,000	"	"	"
0.7	"	"	1:10,000	"	"	"

To each tube is added 0.5 c.c. of normal salt solution and 0.5 c.c. of 7.5 per cent suspension of cells. The tubes are well mixed and in-

cubated at 37.5° C. for an hour. The smallest dose of saponin which yields complete hemolysis is the "hemolytic unit"; in conducting the main test 1 or 1½ units of saponin may be used.

Hauptmann then conducts the test as follows:

(1) One unit of saponin solution, plus 0.8 c.c. of normal cerebrospinal fluid and 0.5 c.c. corpuscle suspension.
(2) Same, using 0.8 c.c. of cerebrospinal fluid for examination.
(3) Same, using 0.8 c.c. of normal salt solution instead of cerebrospinal fluid.

The tubes are mixed thoroughly and incubated for one hour at 37.5° C. Weak reactions show some inhibition of hemolysis in tube No. 2, which may completely disappear with more prolonged incubation; strongly positive reactions show marked inhibition of hemolysis which remains unchanged for 24 hours.

I usually conduct the test with 0.2, 0.4, 0.6, 0.8 and 1.0 c.c. of cerebrospinal fluid and 1½ units of saponin, and read the reaction immediately after the period of incubation and when the controls show complete hemolysis.

Lactic Acid.—Traces of lactic acid may be found in normal cerebrospinal fluid (0.03 per cent) and an increase in lactic acid in eclampsia, epilepsy, hydrocephalus and meningitis of tuberculous and meningococcic origin. Mestrezat found the quantity of lactic acid increased in tuberculous meningitis (0.046 to 0.161 per cent) and also in meningococcus meningitis.

PERMEABILITY OF THE MENINGES AND CHOROID PLEXUS UNDER NORMAL AND PATHOLOGICAL CONDITIONS

As the cerebrospinal fluid is normally derived from two principal sources, namely, as a secretion of the choroid plexus and possibly as a more or less selective filtration of fluid from the vessels of the meninges, the possibility of bacteria, immune sera and drugs introduced into the body fluids reaching the cerebrospinal fluid has long been a question of great interest and importance.

Bacteria.—The method of infection of the cerebrospinal meninges with the meningococcus, pneumococcus, influenza bacillus, and the virus of poliomyelitis is generally regarded as a direct infection along the lymphatics from some primary focus in the upper air passages or accessory sinuses. In tuberculous and syphilitic meningitis, as also in those exceptional infections with typhoid and colon bacilli, and probably also in a percentage of those infections first mentioned and regarded as a direct extension to the meninges, it would appear that the microörganisms may

be primarily in the blood and later lodge in the tissues of the cerebrospinal system, finally gaining access to the fluid itself. In explanation of these infections it is necessary to assume, in the first place, that certain groups of bacteria possess a selective affinity for these tissues, as the meningococcus and virus of poliomyelitis, and, secondly, that they are able to permeate the barrier of endothelium of the meninges or plexus by their own activities. It may be that they are swept into the fluid by physiological filtration from the vessels and tissues, or into the inflammatory exudation which they excite. In the experiments of Flexner and Amoss with the virus of poliomyelitis, it was found that normally the meningeal-choroid plexus complex is capable of excluding the circulating virus from the central nervous organs, but that spinal puncture and the injection of aseptic fluids, which irritate or even slightly alter the integrity of the meninges and plexus, diminish or remove their protective function. In my opinion, therefore, while the settling of microörganisms in these tissues may involve the vital and biological phenomena of tissue, affinity by microparasites, the mere presence of bacteria in the fluid is largely dependent upon physical factors.

Sera.—A portion, at least, of normal or immune serum of a lower animal, introduced into the blood stream, must circulate through the vessels of the meninges, but in many instances it would appear unable to permeate the vessel walls or barrier of endothelium of the plexuses and meninges into the cerebrospinal fluid itself. For example, antimeningococcic serum administered intramuscularly, or even intravenously, does not appear at all or in but traces in the cerebrospinal fluid and certainly in insufficient amounts to influence appreciably the local infection of the meninges. The treatment of cerebrospinal meningitis with immune serum was an acknowledged failure until the serum was injected directly into the spinal canal. Likewise, in the treatment of tetanus, a very important part of the serum therapy consists in the intraspinal injection of tetanus antitoxin, where it neutralizes more effectively the tetanus toxin in the tissues of the spinal cord.

The detection of an alien serum introduced into the body fluids by subcutaneous, intramuscular or intravenous injection has been made possible by immunological reactions, such as precipitation of protein and anaphylaxis. At best, only traces of serum have been found, but this may be due primarily to high dilution of the serum in the body fluids, to the limits of delicacy and to the possibility of error in biological experiments *in vitro*. The problem of permeability of the plexus and meninges to antisera cannot be elucidated on the basis of therapeutic efficacy alone, because of other modifying factors, as high dilution of the serum in the body fluids and its rapid elimination by the kidneys, but it would appear necessary at present to postulate that the plexuses and meninges hold back

at least certain constituents of an antiserum—notably the proteins, which are believed to carry the immune principles.

Chemicals.—Since the advent of salvarsan in the treatment of syphilis, the question of the entrance of this drug into the cerebrospinal fluid has received much attention, particularly in relation to the treatment of paresis, tabes and cerebrospinal syphilis. As will be pointed out later, the results of various examinations for salvarsan itself or for arsenic in the fluid after intravenous injection have been very conflicting. It is definitely known, however, that certain chemicals gain ready access to the cerebrospinal fluid, particularly those that are volatile and lipoid solvents, such as alcohol, acetone and chloroform.

Alcohol has been found in the cerebrospinal fluid in acute alcoholism by Schottmüller and others, and quickly disappears after ingestion has ceased; even after the consumption of large amounts it is absent, or present in only minute traces twenty-four hours later.

Chloroform has been found in the fluid by Widal and Sicard after anesthesia, in amounts varying from 0.01 to 0.012 per cent or 0.100 to 0.120 grams per liter.

Acetone and diacetic acid have been found in the fluid during diabetic coma.

Urotropin has been demonstrated in the fluid after oral administration by Cushing and Crowe, Ibrahim and others, but the high hopes that were entertained of its curative value in poliomyelitis and suppurative meningitis have not been realized.

The presence of various salts in the cerebrospinal fluid has been extensively studied. The *iodids* have been studied with particular interest in relation to the treatment of syphilitic and tuberculous infections of the cerebrospinal tissues and the administration of the sodium and potassium salts generally gives positive results. *Bromids* have been found in the fluid by Redlich, Pötzl and Hess after prolonged administration in epileptics; others, as Vega and Gonzales, Subsol, Orifici and Voisin found only minute traces or none at all. *Nitrates of sodium and potassium, salicylates* and *ferrocyanids* have been found by various observers in the fluid. According to Mestrezat, nitrates are found particularly in the cerebrospinal fluid in a large proportion of cases of meningitis of tuberculous, syphilitic or meningococcic origin. After the administration of one gram of sodium nitrate per 30 kilos of body weight, examination of spinal fluid drawn three hours later showed from 28 to 75 milligrams per liter of fluid in many cases, while the normal amount is from 8 to 10 milligrams per liter of fluid. As far as I am aware, no further attempts have been made in this field comparable to the kidney functional tests, although it would seem to offer an opportunity for useful research.

Arsenic has received particular attention since the advent of salvarsan

in the treatment of syphilis, and especially so in relation to infection of the cerebrospinal tissues. Kopke claims to have found arsenic in the fluid after the administration of atoxyl. Sicard and Block found arsenic in the fluid one hour after the intravenous injection of salvarsan, while twenty-four hours later none was found. Balzer and Condat report finding arsenic in the fluid two days and Ravaut three to eleven months after the administration of salvarsan. Wechselmann, Zaloziecki and Frühwald, Frankel-Heiden and Navassart and others also report finding traces of arsenic after the injection of salvarsan in a small proportion of cases, while Camp and others reported uniformly negative results. Most of these investigations were made with the Marsh-Bertrand apparatus, and with cultures of Penicillum brevicaule after the method of Abel.

At most it would appear that only traces of arsenic are to be found in the fluid after the administration of salvarsan. More constant findings are probably impossible, due to the high dilution of 0.4 to 0.6 gm. of salvarsan in the body fluids, the facility of examining but relatively small amounts of fluid, the lack of delicacy of chemical methods and probably to some extent to the failure of filtration or excretion of arsenic into the fluid. These results have led Swift and Ellis and others to attempt the treatment of syphilis of the cerebrospinal tissues with salvarsan by intraspinal methods.

Mercury has been found in the fluid by Viron in a case of chronic mercurialism; others have failed to find it after ordinary administration.

According to the investigations of Besnard and Troissier, Mosny and Malloizel *lead* is not to be found in the cerebrospinal fluid, except in a few instances of lead meningitis, and then only in mere traces.

The problem of the passage of *dye-stuffs* into the cerebrospinal fluid has attracted but little attention. Widal, Sicard and Monod have found that methylene blue is passed particularly in tuberculous meningitis. It would appear that this constitutes a subject of much importance and worthy of investigation, particularly from the standpoint of chemotherapy.

I shall consider the presence of *antibodies* and other biochemical substances in the cerebrospinal fluid in normal and pathological conditions under the Biochemical Properties and Serology of Spinal Fluid.

Relation of Permeability to Treatment of Diseases of the Cerebrospinal System.—That substances may pass from the blood and other fluids into the spinal fluid of the subarachnoid space is certain, as shown by the presence of dextrose and its increase during diabetes mellitus, by antisheep hemolysin in paresis and also by the passage of alcohol, acetone, chloroform and certain salts as the chlorid of sodium, nitrates and iodids. In any discussion on the question of permeability and selective filtration of the plexuses and meninges, it is important to remember the high dilution of any

drug in the body fluids and the difficulties of chemical research with small amounts of spinal fluid.

In regard to therapy with chemical agents, it would appear that dosage, and hence concentration, of the drug in the blood stream is of primary importance. Even though salvarsan is discriminated against by the mechanism governing the production of cerebrospinal fluid, the spirochetes are in the tissues of the brain and cord and not necessarily on the surface of the meninges bathed in the fluid. In the tissues they should be, and no doubt are, approachable by salvarsan in the blood and other body fluids and the superior claims made for intraspinal therapy in syphilitic infections of the cerebrospinal system may be due to the fact that relatively larger doses may be given by this route. In addition, other factors, such as pleocytosis due to irritation resulting from intraspinal injections and the filtration or secretion of fluid containing salvarsan to replace that which has been drawn, as suggested to me by my colleague, Dr. G. M. Dorrance, may in part explain the good results of the intraspinal treatment of luetic infections.

In the treatment of meningococcic meningitis and tetanus with the respective immune sera, the question of dilution of the serum in the blood stream and its rapid elimination by the kidneys would appear of less importance than the apparent holding back of the protein of the immune serum by the secretory and filtrative processes of the cerebrospinal system. In meningitis the infection is truly of the meninges and it would appear necessary to have the antibodies of the immune serum directly in the spinal fluid; in tetanus, however, the toxin exerts its effects principally upon the cells of the anterior horn. In the treatment of epidemic cerebrospinal meningitis, therefore, the intraspinal injection of the immune serum is the only logical method of attacking the active lesions, since the microörganisms, leukocytes and antibodies are brought into direct relationship; in tetanus the good results following the intraspinal injection of antitoxin are to be explained rather upon the fact that absorption of relatively large amounts of antitoxin takes place with consequent bathing of the susceptible nerve cells and neutralization of the soluble tetanus toxin.

Since experiments in poliomyelitis have indicated that the intraspinal injection of sterile but irritating fluids may hasten infection of the central nervous organs by facilitating the passage of microparasites from the blood to these tissues, the physician should aim to inject only such remedies as are known to possess curative properties for the particular infection under treatment.

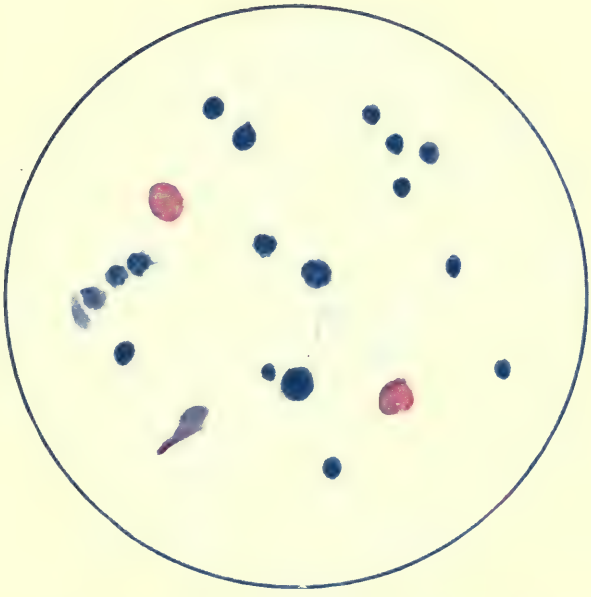

PLATE I.—CYTOLOGY OF CEREBROSPINAL FLUID.

Sediment from the cerebrospinal fluid of a case of paresis, stained with Pappenheim's fluid after the method described in the text. The majority of the cells are of the small lymphocyte variety.

CYTOLOGY OF NORMAL CEREBROSPINAL FLUID

Examination of cerebrospinal fluid for the total number and character of its cells possesses great value in the diagnosis of cerebrospinal diseases. When properly collected and free of blood, normal fluid contains a few

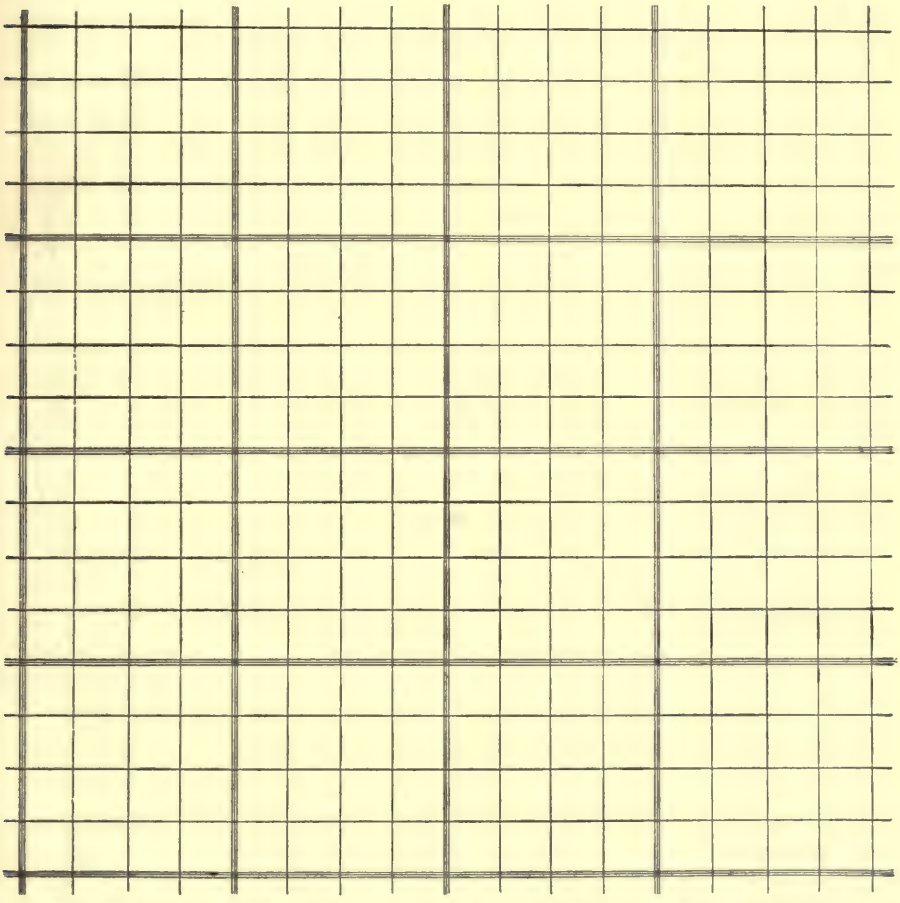

FIG. 84.—THE RULED SPACE OF THE FUCHS-ROSENTHAL COUNTING CHAMBER. The chamber is 0.2 mm. in depth and with the cover glass in position holds 3.2 cubic millimeters of fluid.

small lymphocytes; very occasionally a few large lymphocytes and an occasional endothelial cell. The lymphocytes are small, poor in protoplasm, and the nucleus, which is round or oval and stains intensely basophilic, practically fills the entire cell (Plate I). The endothelial cells are larger; the nucleus stains less darkly and is surrounded by a wall of protoplasm which may be drawn out in a tail-like prolongation.

The normal number of cells per cubic millimeter of fluid, as counted in the Fuchs-Rosenthal chamber, ranges from 0 to 8; 10 to 12 cells per c.mm. is suggestive of a pathological condition; over 15 cells may be accepted as definitely pathological. The term "pleocytosis" is commonly

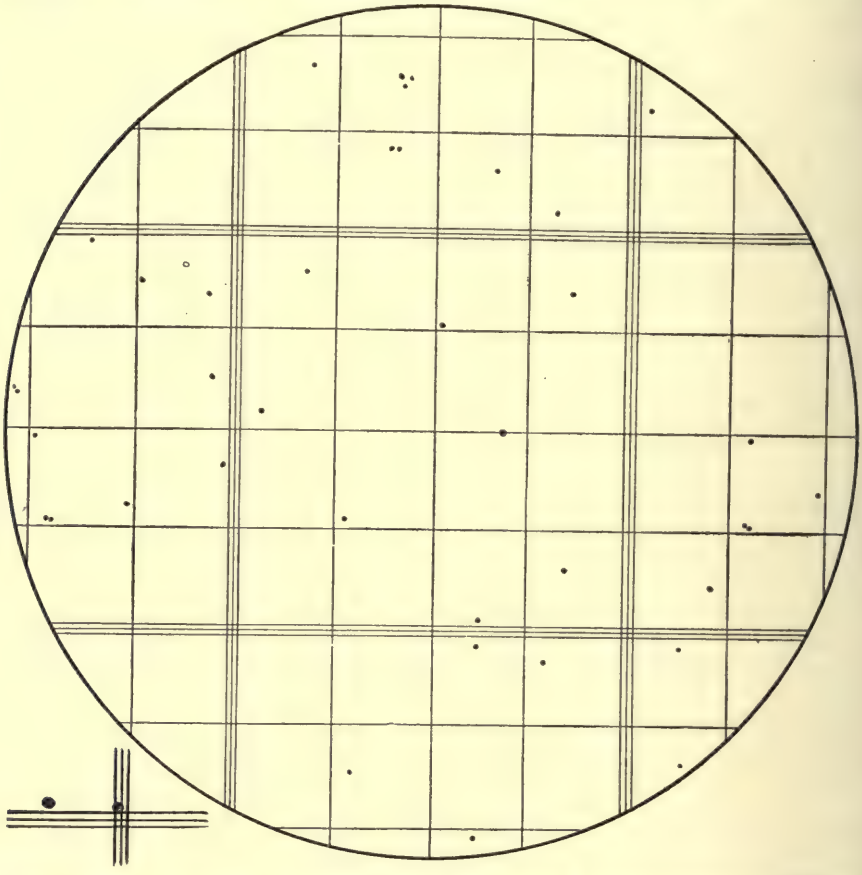

FIG. 85.—TOTAL CELL COUNT OF CEREBROSPINAL FLUID WITH FUCHS-ROSENTHAL CHAMBER.

The large figure shows the appearance of a microscopic field (B. & L. ⅔ objective, No. 5 eyepiece) with cerebrospinal fluid from a case of acute anterior poliomyelitis, diluted as described in the text. The count showed the presence of 180 cells (over 90 per cent being small lymphocytes) per cubic millimeter of undiluted cerebrospinal fluid. The small left-hand figure shows a section of the same field under higher magnification (B. & L. ⅙ objective with No. 5 eye-piece).

used to indicate an increase of the number of cells. After death the number of cells increases and their morphology undergoes some changes.

Methods of Cell Examination.—TOTAL CELL COUNT.—Various methods have been advocated for counting the total number of cells in a unit volume cerebrospinal fluid, but the counting chamber of Fuchs-Rosenthal has proven quite reliable and acceptable (Fig. 84).

1. The fluid should be examined *fresh* and as soon as possible after collection before the formation of fibrin coagula.

2. The fluid must be *free from blood* and for this purpose should be collected in two test tubes, as previously mentioned in the description of the methods of protein determination.

3. After gently shaking the fluid to ensure an even mixture draw diluting fluid to the mark "1" in a white corpuscle pipet and to "11" with the cerebrospinal fluid.

The diluting fluid is prepared as follows:

Glacial acetic acid	2.0 c.c.
Formalin (40 per cent)	3.0 c.c.
Distilled water to	100.0 c.c.
Mix and add:	
Crystals of methyl violet	0.1 gm.
Filter before use.	

This fluid will hemolyse any red corpuscles that may be present and stain the remaining cells.

4. Holding the fingers over both ends of the pipet to prevent leaking, shake for at least two minutes.

5. Expel two or three drops and place a large drop from the bulb of the pipet on the counting disk of the Fuchs-Rosenthal chamber.

6. Adjust the cover glass so that there is no fluid in the moat and Newton's color rings are seen.

7. After waiting at least five minutes to permit the cells to settle on the lines, count all the cells in the entire ruled off space, using a 2/3 or 1/6 objective and a high eye-piece. (Fig. 85.)

8. Multiply the cells counted by 11 and divide by 32; this gives the total number of cells in one cubic millimeter of undiluted fluid.

Counts may be made in the same manner with the ordinary Thoma-Zeiss counting chamber, but are less accurate. All of the cells are counted in the entire ruled-off space (400 small squares), multiplied by 100 and divided by 11 if the fluid has been diluted as described, or multiplied by 10 if undiluted fluid has been used. The result is the number of cells per cubic millimeter of fluid.

On the continent in Europe the "French" method is frequently used. This consists in centrifuging the fluid at high speed and staining a drop of the sediment on a glass slide, from which an idea is formed of the total number of cells present.

Nissl, who advocated a similar method, goes over the entire preparation and simply judges whether the number of cells is normal, borderline, or increased.

Differential Cell Count.—The purpose of this method is to stain the cells for microscopic inspection and classification.

1. Centrifuge 4 to 10 c.c. of fluid at high speed in an electric centrifuge from 15 to 30 minutes.

2. Pour off the supernatant fluid and transfer one to two drops of sediment to a clean slide by means of a capillary pipet. These drops should be gently spread in order to avoid, as far as possible, breaking the cells.

3. Dry in the air; fix for five minutes with pure methyl alcohol or a saturated watery solution of bichlorid of mercury. Wash in water.

4. Stain for several minutes with Pappenheim's fluid:

Saturated aqueous solution of methyl green.....3 parts
" " " " pyronin .....1 part

5. Wash in water; dry, examine with oil immersion lens (Plate I).

Good preparations are secured by staining the smears with Wright's stain and in exactly the same manner as used in blood staining. These preparations should be made before a fibrin coagulum has formed in the fluid. This may be prevented by adding to 5 to 10 c.c. of fluid 1 to 2 c.c. of a 2 per cent solution of sodium citrate in normal salt solution at the time the fluid is drawn. If a coagulum has formed, a portion should be carefully teased out on a slide, dried in the air and stained as above. Many cells are usually enmeshed in the fibrin and a good idea of the cytology may be gained.

For a more accurate differentiation of the cells in the cerebrospinal fluid the *method of Alzheimer* is recommended. This consists in adding to 10-20 c.c. of fluid in a conical centrifuge tube 3 to 4 c.c. of 96 per cent alcohol to precipitate the protein; centrifuge at high speed from 30 to 45 minutes; draw off the supernatant fluid as thoroughly as possible and dehydrate the small mass by adding absolute alcohol, ether-alcohol and ether respectively at intervals of two hours. The sediment is then loosened, imbedded by adding thin and then thick celloidin and mounted on a block. Sections are cut 15 microns in thickness, treated with methyl alcohol to remove the colloidin, stained for one minute with Unna's carbol-methyl-green-pyronin, washed with water, absolute alcohol and xylol and mounted in Canada balsam.

Cytodiagnosis.—This term refers to the diagnosis of cerebrospinal diseases according to type and predominance of the cells present. For example, an increase of small lymphocytes in a clear fluid, from a child presenting symptoms of chronic meningitis, is suggestive of tuberculous meningitis; an excess of polymorphonuclear cells is characteristic of an acute suppurative meningitis; endothelial cells are found particularly in serous meningitis. A suitably stained preparation is carefully examined with the oil immersion lens and a record made of the number and kinds

of the various cells encountered in consecutive fields until 100 or more have been counted. The percentage of each variety of cell is then computed.

CYTOLOGY OF THE CEREBROSPINAL FLUID IN DISEASE

In diseases of the cerebrospinal system the number and character of cells in the cerebrospinal fluid undergo variations of diagnostic and prognostic import. For this reason total and differential cell counts are of much value and should be part of the routine examination of cerebrospinal fluids.

Total Number of Cells.—As previously emphasized, fluids for total cell count should be fresh and free of coagula and blood. The presence of even traces of blood will increase this count and alter the proportion of different cells by reason of the leukocytes introduced. The few red corpuscles which may be present are of no moment as they are hemolysed by the diluting fluid. With the Fuchs-Rosenthal chamber, normal fluids will usually show a few lymphocytes in each cubic millimeter of fluid, though occasionally none are found. The normal limits may be placed at 8 cells per cubic millimeter; most German investigators place the normal at about 5 cells.

Normal ..... 0– 8 cells per c.mm.
Borderline .....10–12 " " "
Pleocytosis .....15 and over cells per c.mm.

Borderline counts are usually found in early or mild organic diseases of the cerebrospinal system, particularly those of luetic origin such as paresis and tabes dorsalis, also in early gumma and in tumors of the brain or spinal cord.

Infective meningitis, such as epidemic cerebrospinal meningitis, usually shows very high counts; low or borderline counts may be found in the convalescent stages and in early tuberculous meningitis.

Definite pleocytosis which may reach very high counts is found in a large number of cerebrospinal diseases—particularly in the infectious meningitides, meningococcic, pneumococcic, tuberculous, and cerebrospinal syphilis, paresis, tabes dorsalis, brain abscess, multiple sclerosis and herpes zoster. I shall later discuss this phase when considering in more detail various spinal diseases.

Kinds and Significance of Cells.—*Differential Counts.*—The examination of stained smears of the cellular elements of cerebrospinal fluid is of most practical importance in the diagnosis of meningitis of infectious origin when polymorphonuclear leukocytes predominate.

In the chronic organic diseases, such as paresis and tabes, the majority of cells are lymphocytes, usually of the same variety. Occasionally distinctive tumor cells may be found which aid in the diagnosis of this condition. The cells in the fluid have been subjected to very careful study and many varieties described. Rehm mentions the following: lymphocytes, large lobed lymphocytes, tailed lymphocytes, large tailed lymphocytes, vacuolated cells, macrophages, plasma cells, tailed plasma cells, erythrocytes, neutrophilic leukocytes, eosinophilic leukocytes, granular cells (plasma cells?) with Schridder's granules, fibroblasts and fibroblast-like cells. Many of these different forms can usually be recognized only by very careful study with the Alzheimer method and special stains. The ordinary technic as previously described suffices for the purposes of diagnosis.

Small Lymphocytes.—These cells are found in normal fluid and undergo increase, particularly in paresis, tabes, cerebrospinal syphilis, multiple sclerosis and tuberculous meningitis, and may be found in small numbers in extramedullary and intramedullary spinal cord tumors. During an attack of herpes zoster they may be found in increased numbers, and both Hebb and Steward have found them in the fluid in chronic lymphatic leukemia. They constitute the most common type of cells found in the fluid. These cells are about the same size as an erythrocyte; the nucleus is round or oval and rich in chromatin, so that they stain intensely blue, the nucleus practically filling the entire cell.

Large Lymphocytes.—These cells are four to five times larger than the small lymphocytes, with a rounded nucleus which stains less deeply and is surrounded by a wide margin of protoplasm. Occasionally cells of this variety show an irregular contour and tail-like prolongation; they are found particularly in fresh or acute processes and show at times a lattice-work or vacuolated appearance of the protoplasm.

Plasma Cells.—Plasma cells, which are found particularly in progressive paralysis, often in cerebral syphilis and in tuberculous meningitis, are about of the same size as small lymphocytes, with a round deeply staining nucleus surrounded with a well-defined, reddish stained protoplasm. Fischer has described these cells particularly in paresis, but also in tabes, cerebrospinal syphilis and paralytic dementia.

Polymorphonuclear Neutrophilic Leukocytes.—Polymorphonuclear neutrophilic leukocytes, which are found particularly in acute suppurative diseases, such as the acute meningitides, brain abscess and similar conditions, and seldom in normal fluid unless mixed with blood, resemble and probably are the polynuclear neutrophilic leukocytes of the peripheral blood. In acute tuberculous meningitis, polynuclear cells may be found although in the chronic stages there are fewer polynuclear cells and more lymphocytes.

Eosinophilic Leukocytes.—Eosinophilic leukocytes, which are best seen in smears stained with a polychrome dye, such as Wright's blood stain, bear a close resemblance to the eosinophils of the blood. They may be found in acute processes; Grund found large numbers (8 to 10 per cent) in a case of cysticercus disease.

Origin of Cells.—With the exception of the lining endothelial cells of the meninges and plexuses and newly formed tumor cells, the cells found in cerebrospinal fluid are derived from the surrounding blood vessels and tissues by a process of diapedesis. I cannot discuss here the various views held regarding the source of the different varieties of lymphocytes, plasma cells, fibroblasts and other cells; they are present in the tissues of the cerebrospinal system in obedience to the same rules that govern their development and presence in pathological conditions in other parts of the body, as the result of different agencies, of which may be mentioned positive chemotaxis, mechanical washing into the fluid by the tissue juices, exudation of serum from blood vessels and exfoliation.

Cytology in Relation to Treatment.—In the treatment of epidemic cerebrospinal meningitis with antimeningococcic serum, total and differential cell counts are of value as indices of the severity of the infection and the efficacy of treatment. As improvement occurs the meningococci become fewer and more intracellular, while the total number of cells and the percentage of polynuclears decrease. Likewise, in the treatment of syphilitic infections of the central nervous system by the intravenous or intraspinal injection of salvarsan, the influence upon the total cell count constitutes a valuable therapeutic guide, a progressive decrease indicating a favorable prognosis.

THE "FOUR REACTIONS" OF NONNE

The now famous term "Four Reactions" of Nonne refers to the following tests of cerebrospinal fluid: a protein reaction (Nonne-Apelt Phase I or other reaction), a total cell count, a Wassermann reaction with spinal fluid and a Wassermann reaction with blood serum. These tests have been especially used in the diagnosis of syphilitic disease of the central nervous system, as paresis, taboparesis, tabes dorsalis and cerebrospinal syphilis, and as a guide to treatment. The efficacy of treatment is usually shown by a decrease in the cells, followed by a decrease in protein, and lastly by influencing the Wassermann reactions with fluid and serum. To these tests Lange's colloidal gold test may be added, particularly in the diagnosis of paresis.

The accompanying chart (Fig. 86) has proved useful to me for pur-

poses of record of an ordinary examination of cerebrospinal fluid and is of such size as may be filed with case histories.

MASSIVE COAGULATION AND XANTHOCHROMIA

(*The Compression Syndrome*)

Within recent years numerous reports have been made regarding peculiar changes in the cerebrospinal fluid observed in conditions with stasis of the fluid by a space-restricting process, such as tumors and chronic inflammatory processes of the spinal meninges and adjacent structures causing compression of the cord. The main characteristics of the fluid are as follows:

(1) A deep yellow color is present (xanthochromia); (2) the fluid tends to undergo spontaneous coagulation immediately after withdrawal or in the course of a few hours (massive coagulation); (3) the fluid contains a very large amount of protein; and (4) the cell content may be normal or but slightly increased.

The spinal fluid pressure may be normal, but is usually increased; the fluid is limpid and of increasing viscosity; the protein content is always high, ranging from 0.62 to 2.7 grams or more per 100 c.c.; albumoses and peptones and other products of protein hydrolysis are usually present; the fluid is rich in fibrinogen and fibrin which bring about early, spontaneous and characteristic coagulation; the sugar content may be normal, but is usually slightly increased (0.07 to 0.08 per cent); the sodium chlorid content is slightly decreased (0.693 to 0.710 per cent); the total cell count is low and the few cells found are usually of the lymphocyte variety.

In not a few cases of cord compression, the fluid may be colorless and not undergo spontaneous coagulation, but yet contain a greatly increased amount of protein with few or no cells. Mestrezat recognizes this as a mild degree of the same condition and found it especially in Pott's disease. This condition of the fluid is generally known as the "syndrome of Froin." Mestrezat has collected 21 cases from literature and Raven, writing later, collected 71 cases 22 of which were his own. Recently Ayer has reported 9 cases of his own, all presenting symptoms of more or less complete transverse myelitis. It is the consensus of opinion that this syndrome is an important aid to the diagnosis of cord compression, and most characteristic of fluid drawn from beneath tumors of the spinal cord. Other conditions causing intramedullary or extramedullary compression, such as Pott's disease, injuries and chronic localized meningitis, may, however, be the underlying cause. I have seen the fluid drawn from below inspissated pus in the spinal canal present all of the characters

CEREBROSPINAL FLUID EXAMINATION

Name: *Age:* *Ward:* *Date:*

Clinical Diagnosis: *Physician:*

Pressure	Amount	Physical Properties	Cells per c. mm.	Differential Cell Count			Protein Tests			Wassermann Reaction	
				Lymph.	Polys.	Endothel.	Pandy	Noguchi	Kaplan	Blood	Spinal Fluid

Colloidal Gold Reaction

Registry No.	Color Reactions	Dilutions of Spinal Fluid										Remarks
		1 1 : 10	2 1 : 20	3 1 : 40	4 1 : 80	5 1 : 160	6 1 : 320	7 1 : 640	8 1 : 1280	9 1 : 2560	10 1 : 5120	
5	Colorless											
4	Pale blue											
3	Blue											
2	Lilac or purple											
1	Red-blue											
0	Red—unchanged											

Bacteriological Examination

Smears: *Culture:* *Animal Inoculation:*

Additional Chemical Examinations

Quantitative Dextrose: *Quantitative Protein:* *Quantitative Chlorids:*

Examined by:

FIG. 86.—CHART USED BY THE AUTHOR FOR RECORDING THE RESULTS OF EXAMINATION OF CEREBROSPINAL FLUID.

described. The essential features in the production of this fluid are a closed cavity under pressure and venous stasis, causing petechial hemorrhages or transudation, the latter probably being the more important. The lesion may be situated in the cervical, thoracic or lumbar region, but is more usual in the lumbar or lower thoracic. The yellow color is ascribed to hemoglobin, although Froin, Foy, Blanchetière and Lejonne consider it a derivative of biliary pigment.

Briefly then, fluid showing massive coagulation and xanthochromia is usually found in patients with chronic lesions causing compression of the cord, with consequent stasis of the fluid and increased transudation of serum and hemoglobin from congested blood vessels, giving the fluid a yellowish color if the condition be of sufficient duration, and an increased content of protein and fibrinogen without an increase of cells.

SEROLOGY OF CEREBROSPINAL FLUID

Antibodies

Hemolysins.—The Hemolysin Reaction of Weil and Kafka.—The normal spinal fluid does not contain hemolytic complement or any of the natural antibodies that may be present in the blood. Present in the blood serum of a large percentage of normal persons are variable amounts of natural antisheep hemolysin, an antibody, which, in the presence of complement, will cause the hemolysis of sheep erythrocytes; this antibody is not found in the normal spinal fluid. Weil and Kafka found that the cerebrospinal fluids of about 87 per cent of paretics may contain this hemolysin, thereby indicating an increased permeability of the meninges, and have advocated the following test in the diagnosis of paresis, which has been reported upon favorably by many. In about 10 per cent of paretics a trace of hemolytic complement may also be present; in acute suppurative meningitis both the hemolysin and complement may be found. The test may be conducted as follows:

1. Into two test tubes place 3 c.c. of *fresh* cerebrospinal fluid (not over 6 hours old) and normal salt solution, respectively. To each add 1.0 c.c. of a 2.5 per cent suspension of washed sheep corpuscles; mix and incubate at 37° C. for two hours. Hemolysis in the first tube indicates a positive reaction, namely the presence of both antisheep hemolysin and hemolytic complement. The second tube is a control and should show no hemolysis.

2. In testing for the hemolysin alone the fluid need not be fresh, but should be tested soon after collection. Into a centrifuge tube place 5 c.c. of fluid and 1 c.c. of a 2.5 per cent suspension of sheep cells; mix and

place in the refrigerator for an hour to permit the union of hemolysin with the cells. Centrifuge the mixture; remove the supernatant fluid and to the sedimented cells add 1 c.c. of fresh guinea-pig complement serum diluted 1:20 (0.05 c.c. undiluted serum). Mix and reincubate for an hour or two. At the same time incubate 1 c.c. of the corpuscle suspension and 1 c.c. of the diluted complement serum as a control. The appearance of hemolysis in the first tube indicates a positive reaction, namely, the presence of the antisheep hemolysin. The test may also be conducted by simply mixing in a test tube 5 c.c. of fluid, 1 c.c. of corpuscle suspension and 0.1 c.c. undiluted guinea-pig complement serum and incubating for an hour or two. As previously mentioned, *complement* is not present in normal cerebrospinal fluid; traces may be found in acute suppurative meningitis and in about 10 per cent of paretics. According to Zaloziecki, the presence of fibrinogen and complement in cerebrospinal fluid runs parallel in both, indicating that both are derived from the blood.

Precipitins and agglutinins for various bacteria and blood cells are not to be found in normal fluid. During disease when the amount of these antibodies reaches a high concentration in the blood, traces may be found in the cerebrospinal fluid, as for example in typhoid fever. Vincent and Bellot have described a precipitin reaction in epidemic cerebrospinal meningitis. To 50 or 100 drops of fluid, clarified by centrifugalization, is added a drop of antimeningococcic serum and the mixture incubated for two hours. After eight to fifteen hours, the presence of a precipitate indicates the presence of meningococcic meningitis.

Bacteriolysins are not found in normal spinal fluid, but may be present when their concentration in the blood stream is high and during suppurative meningitis with the disintegration of leukocytes.

The **Wassermann antibody or reagin** may be found in the cerebrospinal fluid in all but the primary stages of syphilis and particularly in tertiary syphilis of the central nervous system. Usually these antibodies are present in both the blood serum and spinal fluid, sometimes in the fluid alone. While the term *antibody* is applied to the substance yielding fixation of complement in the Wassermann syphilis reaction, this is probably a misnomer. It would appear that it is a product of cellular activity or disintegration due to the presence and activity of Treponemata pallida and not a true antibody in the usual meaning of the term.

Toxins and antitoxins are only exceptionally found in the spinal fluid. The normal fluid is without toxicity when injected into the lower animals. In diphtheria and tetanus traces of toxins may be found in the fluid when the patient is profoundly toxic; likewise antitoxin, even when injected intravenously, may reach the fluid only in traces. This is true of the antisera in general, and for this reason antimeningococcic serum and tetanus antitoxin serum are injected intraspinally.

WASSERMANN REACTION

In 1906 Wassermann and Plaut first applied the method of complement-fixation with the cerebrospinal fluid of paretics. Of 41 specimens studied, 32 reacted positively, 4 doubtfully and 5 negatively. This work was the beginning of what has since proved to be one of the most valuable diagnostic aids known to medical science.

There are abundant observations to prove that the antigen in the Wassermann reaction is in reality of the lipoidal substances that are present and independent of Treponemata pallida. The specificity of the reaction depends upon the peculiar nature of the Wassermann antibody or "reagin" which possesses this ability to fix or absorb complement in the presence of a suitable emulsion of a lipoid or lipoids, and not upon the question of specificity of the antigen, as Bordet demonstrated in regard to his bacterial antigen or extract of pest bacilli and anti-pest serum.

It is understood, therefore, that the ordinary antigen in the Wassermann reaction need not be an extract of Treponemata pallida or of tissues rich in these microörganisms. Wassermann's original watery extract of syphilitic liver and Noguchi's watery extract of pure cultures of treponemata are specific antigens in the sense that products of the specific microörganism may be present, but practical experience with these extracts, compared with alcoholic extracts of syphilitic and normal tissues, have generally shown the superiority of the latter. As shown by Noguchi and myself, alcohol does not serve well in extracting the antigenic or complement-fixing properties of pure cultures of Treponemata pallida, and while alcoholic extracts of syphilitic liver are fondly called "specific antigens" by some workers in this field, many of whom apply this term to purchased extracts which may, so far as they know, be other than extracts of truly syphilitic livers, it is probable that the actual antigen or complement-fixing substance is a lipoid or lipoids from the liver tissues and not from the treponemata. As I shall point out later, not all extracts of organs serve equally well as antigens in the Wassermann reaction; some serve this purpose better than others and each must be tested out in this capacity before it is acceptable, regardless of whether it be an extract of syphilitic or normal tissue.

What I want to emphasize here is the non-specific nature of the so-called antigen or extract in the Wassermann reaction and the peculiar and more specific nature of the antibody upon which the specificity of this reaction depends. The serum and possibly the cerebrospinal fluid of a syphilitic is characterized by the presence of this lipoidophilic, antibody-like substance, which has a great affinity for lipoids and in a mixture with them will cause the absorption or fixation of complement to a well-marked

degree. In the presence of a suitable lipoid extract, a syphilitic fluid is capable of absorbing or fixing large amounts of complement, and this constitutes the main principle and all that is definitely known of the syphilitic reaction.

The true nature of the Wassermann-Detre reaction, therefore, cannot be said to have been determined. It is probable that the ordinary syphilitic reaction is in itself not dependent upon the true pallidum antibody, but dependent upon the presence of a second kind of substance in the body fluids which has been called "reagin" or Wassermann antibody, in the nature of a peculiar tissue product due to the presence and activities of the spirochetes themselves. In addition to this secondary product, there is probably a true syphilis antibody that may yield truly specific complement fixation with pallidum antigens. In so far as the Wassermann reaction is concerned, the true antibody is entirely secondary in importance, and the whole question is intimately concerned with the chemistry of lipoids. While future researches in immunocolloidal chemistry may reveal the mechanism of the reaction, the principles are at least well understood at present, so that the syphilitic reaction is proving of great diagnostic and practical value.

Specificity of the Wassermann Reaction.—As stated above, the Wassermann reaction is not biologically specific, but practically it possesses a high degree of specificity due to the fact that the peculiar lipoidophilic reagin or Wassermann antibody is found in so few other diseases. This reaction, however, has been so universally used and misused that there are very few diseases in which some investigator has not reported positive results. At present it is known that positive Wassermann reactions may occur in a few diseases other than syphilis, but not to the extent that earlier investigators would have us believe. In most of the diseases yielding positive reactions, such as frambesia (yaws) and leprosy of the tuberous type, the clinical symptoms are so marked that they may readily be differentiated from syphilis, so that in those parts of the world where frambesia does not occur and leprosy is rare, the Wassermann reaction with either serum or cerebrospinal fluid is of unequaled and incalculable diagnostic value. Of great importance, however, is a thorough understanding of the underlying principles of the reaction and its technic, as the majority of positive reactions reported as occurring in the large group of various diseases can be ascribed to faulty technic.

The technic, while comparatively simple, has many sources of error, most of which are uncontrollable, but require a thorough understanding in order that an intelligent and reliable complement-fixation reaction may be secured. Those attempting this reaction should have accurate knowledge of the preparation and standardization of the antigen or extract and know a good from a poor one. I believe the antigen constitutes one of

the most important elements of the reaction and explains the discrepancies among results from different laboratories more than any other single factor. Likewise, the worker should have intimate knowledge of the sources of error dependent upon the serum alone and the various components of the hemolytic system, as complement, hemolysin and corpuscles. The importance of at least chemically clean glassware and other modifying factors should be borne in mind, since they influence the results.

Diagnostic Value of the Wassermann Reaction in Syphilis of the Cerebrospinal System.—The statement is frequently made that a diagnosis of syphilis should not be based upon the results of laboratory examinations. In not a small group of cases, however, the diagnosis cannot be made otherwise. In the latent cases of long standing and in the tertiary stages of syphilis, the Wassermann reaction may be the only available basis upon which to establish a diagnosis. As a diagnostic measure, every safeguard must be placed about the test to avoid non-specific reactions. While it is true that great harm may result from a false positive diagnosis due to faulty technic, yet it must be admitted that the Wassermann reaction is not too delicate, and that we are liable to err on the side of securing false negative reactions. Every effort should be made to render the test as delicate as possible with reliability and specificity; in my opinion this is best secured by the closest attention to the kind and dose of the antigen and, secondly, to quantitative factors in the hemolytic system.

Persons with syphilitic involvement of the cerebrospinal tissues may yield positive reactions with both blood and cerebrospinal fluid, or, what is very important for the surgeon to bear in mind, may react positively with the fluid and negatively with the serum—a matter difficult to explain and believed to be due to the confining of the reacting substances in the subarachnoid space. Occasionally, the reaction may be positive with the serum only, but it is important to remember that before a diagnosis of syphilitic disease of the cerebrospinal tissues can be excluded on the basis of the Wassermann test, both serum and fluid should be examined.

Normal cerebrospinal fluid does not give a positive Wassermann reaction; the fluids of persons suffering with frambesia (yaws) or leprosy may yield a positive reaction in the absence of syphilis. In paresis and taboparesis the blood Wassermann is positive in 90 to 100 per cent of cases; the spinal fluid Wassermann is positive in at least 85 per cent of cases using 0.2 c.c. of fluid after the original method, and in about 92 to 100 per cent of cases using larger doses of fluid (0.8 c.c. or more) after Hauptmann's method (*see* page 198). In tabes dorsalis the blood serum reacts positively in from 96 to 100 per cent of cases; the spinal fluid reacts positively in about 60 per cent unless large amounts of fluid be used (0.8 c.c. or more), when positive reactions are observed in about

87 per cent. In cerebrospinal syphilis the blood serum, and particularly the fluid, will give a positive reaction less frequently than in paresis. In untreated congenital syphilis of children, one year or over in age, the blood Wassermann reaction is positive in from 97 to 100 per cent of cases. As the clinical manifestations may vary and be ill-defined, the serum reaction possesses considerable diagnostic value. Likewise, in congenital mental deficiency and epilepsy the Wassermann reaction shows that syphilis plays a part in the etiology of a small proportion of cases.

In the primary stage of syphilis, the cerebrospinal fluid reacts negatively; in the secondary stage, however, the fluids of a number of cases showing no symptoms referable to the central nervous system have been found by Craig and Collins and Wile to react positively. This indicates that these tissues may be involved comparatively early in syphilis. In gumma of the brain or spinal cord, the Wassermann reaction possesses a very distinct value in diagnosis (*see* page 209).

Provocatory Stimulation.—Occasionally persons are encountered presenting indefinite symptoms of involvement of the tissues of the central nervous system and a negative or doubtfully positive Wassermann reaction, while syphilis is known to have been contracted or is strongly suspected. In these the administration by inunction in a dose of one-half dram of the ointment each day for a period of seven or ten days, *or best of all the intravenous administration of 0.4 gm. of salvarsan, followed two or three days later by a second Wassermann reaction,* may result in securing positive and conclusive results. In a recent excellent paper upon this subject Stokes has emphasized the necessity of conducting the test within three days after the provocatory treatment. This is known as provocatory stimulation and is due probably to the liberation of endotoxins from destroyed treponemata or to their stimulation by a dose of drug that did not suffice to kill them, an analogy to the clinical Herxheimer reaction.

The Wassermann Reaction and Its Relation to Treatment.—Citron originally observed that during the mercurial treatment of syphilis the Wassermann reaction gradually became weaker, and finally disappeared. His observations, which have since been confirmed, showed that the Wassermann reaction may be taken as an index and guide to treatment. It should be the object of treatment not only to dissipate the external and obvious lesions of the disease, but to produce a condition of the blood and cerebrospinal fluid in which the Wassermann reaction is permanently negative.

In my experience it is often an exceedingly difficult matter to influence the blood or fluid Wassermann reaction of well developed cases of syphilis of the central nervous system, especially in paresis and taboparesis, by vigorous treatment with salvarsan or mercury or a combination of these. Objective and subjective symptoms may be relieved or entirely disappear

or the lesions may at least be prevented for a time from further development, but complete cure on the basis of clinical aspects and negative Wassermann reactions is decidedly uncommon. Despite most vigorous treatment with intravenous and intraspinal injections of salvarsan, persistently positive Wassermann reactions are observed with the spinal fluid; when this condition of "Wassermann-fast" reaction occurs with the fluid of a tabetic, Kaplan suspects the development of paresis. The sum total of the experience of investigators from all parts of the world would indicate that a persistently positive reaction means the presence of living Treponemata pallida somewhere in the body, and that treatment should be continued until the blood and cerebrospinal fluid react negatively.

Among cases showing in the spinal fluid (1) a pleocytosis, (2) increased protein content and (3) a positive Wassermann reaction, the pleocytosis is generally first reduced by treatment, then the second and lastly the Wassermann reaction. The latter, therefore, constitutes the most delicate index of treatment. It has been abundantly proved, however, that a single negative reaction with the blood or fluid is not sufficient or definite evidence that a cure has been effected, for the reaction may recur after treatment is discontinued and be followed by clinical evidence of the disease. It is necessary, therefore, that the reactions remain persistently negative over two years before a cure can be declared.

Technic of the Wassermann Reaction.—Fluid to be Tested.—Several cubic centimeters of blood are collected in a sterile test tube or vial by puncture of a vein at the elbow with a proper sized, sterilized needle, with or without a syringe. The Keidel tube is very convenient and to be recommended. In the majority of cases sufficient blood may be secured from the finger after brisk rubbing of the hands to insure free circulation and warmth and puncturing deeply with a broad bladed blood lancet. Cerebrospinal fluid (about 5 c.c.) is collected by spinal puncture and should be free of blood. If blood be present it should be removed by centrifugalization. The blood serum is to be separated after coagulation has taken place and inactivated by heating at 55° C. for thirty minutes. The cerebrospinal fluid is used unheated. Test tubes should be of a convenient size, 12 by 1.5 cm., perfectly clean, free from acids and alkalies, and sterilized. Pipets should be perfectly clean and sterile. Two kinds are required: the ordinary 1 c.c. pipet, graduated to 0.1 or 0.01 c.c. and calibrated to the tip, and 5 c.c. pipets divided into 0.1 c.c. Care should be exercised in handling pipets to avoid breaking the tips. After use they should be washed free from blood and serum.

Complement.—A healthy guinea-pig is anesthetized with ether and the vessels of the neck severed with sharp scissors; the blood is collected in a centrifuge tube with the aid of a funnel or bled directly into a petri dish. In a few hours the clear serum that has separated is transferred by

a pipet to a test tube. If centrifuge tube be used, and this is the procedure I prefer, the coagulated blood should be gently broken up after an hour or so with a sterile glass rod and the serum separated by centrifugalization. This yields a higher output of equally active complement serum. If only one or two reactions are to be conducted, sufficient complement serum (2 to 4 c.c. blood) may be secured from the heart of a large pig by puncture with a No. 22 needle fitted to a syringe. Larger needles may kill the animal. The serum is diluted 1 : 20 (1 part serum + 19 parts normal salt solution) and used in dose of 1 c.c. (= 0.05 c.c. undiluted serum).

Sheep Corpuscles.—Sheep blood is secured from an animal kept for this purpose by puncturing an external jugular vein, or blood may be secured from an abattoir. The blood should be perfectly fresh and defibrinated at once by shaking with glass beads or whipping with a glass rod. After defibrination, a sufficient quantity of blood cells is washed three times in large volumes of normal salt solution and after the last washing the cells are made up in a 2.5 per cent suspension in normal salt solution (1 c.c. sedimented cells and 39 c.c. normal salt solution). Of this emulsion 1 c.c. is used in the titrations and main tests.

Hemolysin.—Antisheep hemolysin is prepared by injecting large healthy rabbits intravenously with 5 c.c. of a 10 per cent suspension of washed sheep corpuscles once every three days until three or four injections have been given. Five days after the last injection 1 or 2 c.c. of blood is secured from the ear and the hemolysin content titrated. If the serum show a sufficiently high titer (at least 1 : 2000) the animal is bled, after ether anesthetization, by severing the large vessels of the neck and collecting the blood into large centrifuge tubes with the aid of a funnel. The serum is then separated and diluted with an equal quantity of pure neutral glycerin. This mixture may be kept in a stock bottle, or better, in separate and sealed 1 c.c. ampoules. For use, the contents of an ampoule (0.5 c.c. serum and 0.5 c.c. glycerin) are diluted in a sterile flask with 100 c.c. sterile normal salt and 0.2 c.c. tricresol added as a preservative against bacterial contamination. This dilutes the hemolysin to practically 1 : 200. This flask of diluted hemolysin is kept in a cold place when not in use and preserves its titer over several weeks of time.

Before being used in antigen titrations or the main tests, the hemolysin is titrated with the complement serum and corpuscle suspension at hand. This constitutes a very important part of complement-fixation technic, as the three components of the hemolytic system—namely, complement, corpuscles and hemolysin—must be accurately adjusted by titration. For this purpose the complement and corpuscles may be used in constant amounts and the smallest dose of hemolysin necessary to effect complete hemolysis determined (hemolysin titration); or the corpuscles and hem-

olysin may be used in constant doses and the smallest amount of complement necessary to effect complete hemolysis determined (complement titration). Either may be used, the underlying and important principle being borne in mind of adjusting the hemolytic system so that quantitative factors may be controlled, since an excess or a decrease of any one of these components will alter the result in a falsely positive or negative way.

In the preliminary titration of hemolysin with serum derived from blood taken from the ear of the immunized rabbit, dilute 1: 100 (0.1 c.c. serum and 9.9 c.c. normal salt solution) and conduct the titration as described in the next paragraph. If all of these tubes show complete hemolysis it is necessary to repeat the titration with a 1 : 500 or 1 : 1000 dilution. These preliminary titrations for some unknown reason usually give a higher titer than the whole serum obtained after bleeding the animal to death. The stock dilution of hemolysin is to be prepared according to the titer, but the one described (1 : 200) usually suffices.

In titrating the hemolysin for Wassermann reactions, place the following amounts of diluted hemolysin (1 : 200) in a series of test tubes: 0.05, 0.1, 0.15, 0.2, 0.25 and 0.3 c.c.; add 1 c.c. of diluted complement serum (1: 20) and 1 c.c. of corpuscle suspension. Shake each tube gently and incubate for an hour at 37° C., when the readings are made. The smallest amount of hemolysin producing complete hemolysis is the *unit;* in conducting the antigen titrations and Wassermann reactions, double this amount, or *2 units,* should be used. In recommending the use of two units of hemolysin after the original method of Wassermann, I am confident that the reactions are sufficiently delicate, providing the readings of the main test are made at the end of the second period of incubation. This is especially true with cholesterinized extracts.

Antigen.—It may be said to be well proved that extract antigens in the Wassermann reaction are not biologically specific, and need not be extracts of syphilitic tissues. The term "antigen," as ordinarily used in the Wassermann reaction, must therefore be regarded as a misnomer. An antigen or extract cannot give reliable or satisfactory results unless it be carefully titrated and its properties determined. Antigen may serve as a frequent source of error when used by those possessing insufficient knowledge of the good and bad properties. The test for the syphilitic reaction should not be undertaken by any one not competent to titrate and judge of the qualities of the antigen to be employed. I have long advocated the use of the following three extracts in conducting the Wassermann reaction: (1) an alcoholic extract of human heart reënforced with cholesterin; (2) an alcoholic extract of syphilitic liver; and (3) an extract of acetone insoluble lipoids from human or beef heart.

An extensive experience has taught me that the "reagin" in different bloods and cerebrospinal fluids may show varying complement-fixing prop-

erties with the lipoids in different extracts of proved value; by using three different extracts more accurate results are possible. Further than this, an extract may lose in antigenic sensitiveness or become more anticomplementary and these changes are less disturbing when three extracts are used instead of dependence being placed upon one. Furthermore, the method permits the use of a cholesterinized extract controlled with non-cholesterinized extracts. In my experience these reënforced antigens have proved most delicate and, when properly titrated and used, very satisfactory, although they are more likely to yield very slight degrees of inhibition of hemolysis with non-syphilitic sera than plain extracts. For the methods of preparing these and other antigens for the Wassermann reaction the reader is referred to special works on the subject.

In diluting an extract with salt solution an effort should be made to secure the maximum turbidity; the amount of each extract required should be carefully figured and placed in a test tube and the salt solution added slowly with a pipet. As a general rule, cholesterinized and acetone-insoluble lipoid extracts require diluting 1 : 20 with normal salt solution and alcoholic extracts of syphilitic liver 1 : 10.

The *anticomplementary titration* is conducted by placing in a series of test tubes increasing amounts of antigen emulsion (1 : 20 or 1 : 10) as follows: 0.2, 0.4, 0.6, 0.8, 1.0 and 1.5 c.c Add 1 c.c. of complement serum (1 : 20) and sufficient salt solution to make the total volume in each tube equal. To each tube may be added 0.2 c.c. of fresh *normal* human serum (heated at 55° C. for half an hour), but this is not absolutely neeessary. Incubate for an hour and add 2 units of hemolysin and 1 c.c. of corpuscle suspension to each tube. Re-incubate an hour or an hour and a half; *the smallest dose of antigen that shows beginning inhibition of hemolysis is the anticomplementary unit.*

A hemolytic control (complement, corpuscle and hemolysin) should always be included and show complete hemolysis; if a normal serum be used it should be controlled to determine that it is free of anticomplementary properties in itself (serum control). This is conducted by incubating 0.2 c.c. serum with 1 c.c. of the complement serum, as above, and adding 2 units of hemolysin and 1 c.c. of corpuscle suspension. After the second period of incubation this tube should show complete hemolysis; otherwise it is unfit.

The *antigenic titration* is conducted in exactly the same manner, except that smaller doses of the diluted antigen are used: 0.05, 0.1, 0.15, 0.2, 0.25 and 0.3 c.c. To each tube add 0.2 c.c. of fresh inactivated serum from an untreated case of syphilis and known to yield a strongly positive Wassermann reaction. Hemolytic and serum controls must always be included and show complete hemolysis. *The smallest amount of antigen emulsion showing complete inhibition of hemolysis is the antigenic unit.*

A good and satisfactory extract is one that is perfectly antigenic in a small dose, 0.1 c.c. of 1:20 dilution, and is not anticomplementary except on large dose, 1.5 c.c. of a 1:20 dilution.

In conducting the Wassermann test it is well to use double the antigenic unit, provided this dose be not more than one-sixth that of the anticomplementary unit. This margin of safety is particularly needed with cholesterinized extracts. In the example just mentioned, the extract could be used in dose of 0.2 c.c. of a 1:20 dilution (double the unit) as this amount is less than one-seventh that of the anticomplementary unit.

The Test.—For each serum or cerebrospinal fluid four test tubes are arranged in a row and marked with the patient's name or initials. The first tube is marked "C. H." and receives the cholesterinized heart extract; the second tube is marked "S" for the alcoholic extract of syphilitic liver; the third is marked "A" for acetone-insoluble lipoids; and the fourth is not marked at all or simply marked with the letters "S. C." (serum control). To each of the four tubes 0.2 c.c. of the patient's serum is added, or 0.8 c.c. of cerebrospinal fluid. To each tube 1 c.c. of the diluted complement (1 : 20) and sufficient salt solution to bring the total volume in each up to 3 c.c. are now added.

Controls.—A known positive and negative serum should be included unless a large number of tests with reliable antigens are performed every week, in which case, among many sera, a few at least are likely to be positive. Under these circumstances these controls may be omitted; as a general rule, however, they should be included. To the hemolytic system control tube 1 c.c. of complement dilution and 2 c.c. of salt solution are now added. Three antigen control tubes are set up for each antigen with the dose employed, plus 1 c.c. of complement dilution and sufficient salt solution to make the total volume about 3 c.c. The corpuscle control receives 1 c.c. of the suspension plus 3 c.c. of salt solution. The antigen, serum or fluid and hemolytic controls are very important and should never under any circumstances be omitted. All the tubes are shaken gently and placed in the incubator for an hour, 37° C. At the end of this time 2 units of hemolysin and 1 c.c. of corpuscle suspension are added to each tube except to the corpuscle control. Each tube is shaken gently and reincubated for an hour or longer, depending upon the hemolysis of the serum controls, when the results are read.

Reading the Results.—The controls should always be inspected first. The hemolytic, antigen and serum controls and known negative serum tubes should all be hemolyzed. The antigen tubes containing the positive syphilitic serum should not be hemolyzed. Results with the unknown sera are dependent upon whether the sera are luetic, and if they be, upon the quantity of syphilis antibody present. With strongly positive sera there is complete inhibition of hemolysis with all three antigens. With

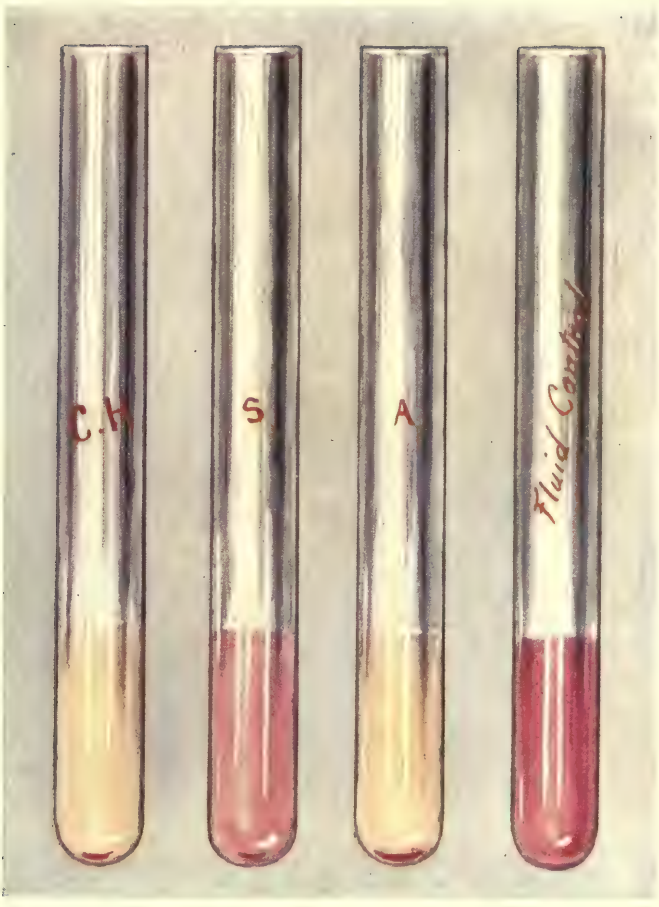

PLATE II.—THE WASSERMANN REACTION EMPLOYING THREE ANTIGENS WITH 0.8 C.C. CEREBROSPINAL FLUID IN EACH TUBE.

++++ reactions are shown with antigens C.H. (cholesterinized alcoholic extract of heart) and A (acetone insoluble lipoids); +++ reaction with S (alcoholic extract of syphilitic liver).

sera of long-standing or treated cases of syphilis containing smaller amounts of antibody the reaction with the cholesterinized extract is usually strongly positive, whereas with the other two antigens the degree of inhibition of hemolysis is less marked and variable (Plate II). In from 15 to 20 per cent of cases the cholesterinized extract shows a 50 per cent or more inhibition of hemolysis, whereas with the other two antigens the reactions are negative. In our experience the majority of such sera were taken from patients giving a frank history of syphilis of many years' standing and from known cases undergoing treatment, further therapy being indicated until the reaction finally became negative on the use of cholesterinized extracts. In a small proportion of cases a feebly positive reaction, of 25 per cent or less inhibition of hemolysis, may be found with the cholesterinized extract alone. Many of these reactions occur with sera of treated cases of syphilis. After a new antigen has been prepared and titrated, it should be tested out in this manner by placing it in the series along with at least two other older antigens of proved value, and used in the examination of a large number of sera before it is finally accepted as reliable.

Various methods have been proposed for recording the results of the Wassermann reaction. The following scheme, after Citron, is widely used:

++++ = complete inhibition of hemolysis = strongly positive.
+++ = 75 per cent inhibition of hemolysis = moderately positive.
++ = 50 per cent inhibition of hemolysis = weakly positive.
+ = 25 per cent inhibition of hemolysis = very weakly positive.
± = less than 25 per cent inhibition of hemolysis = delayed hemolysis or doubtful reaction.
− = complete hemolysis = negative reaction.

Quantitative Wassermann Reaction with Cerebrospinal Fluid.—This test is conducted in exactly the same manner as described above, except that one antigen is used with different amounts of cerebrospinal fluid. Into a series of seven test tubes place increasing amounts of cerebrospinal fluid as follows: 0.1, 0.2, 0.4, 0.6, 0.8, 1.0 and 1.0 c.c.; into the first six tubes place the dose of antigen selected. I use a cholesterinized extract or one of acetone insoluble lipoids in the same dose as used in the preceding method. The seventh tube is the fluid control.

An antigen and a hemolytic control should be set up as described. To each tube add 1 c.c. of complement serum (1:20) and sufficient normal salt solution to make the volumes in the tubes equal. Shake gently and incubate for an hour; add 2 units of hemolysin to each tube, mix and reincubate for an hour or longer, depending upon the hemolysis of the controls, when the readings are made as described. (Plate III.)

Wassermann originally advised using cerebrospinal fluid in 0.4 c.c. or double the dose of serum. Nonne and Holzmann, and particularly Hauptmann and Hoessli, have drawn attention to the fact that, while this dose suffices with the fluid of paretics or taboparetics, it may be insufficient with fluids containing less reagin. For this reason Hauptmann has advised the use of larger doses of fluid in a method practically the same as the quantitative technic described above. Numerous investigators have shown that the maximum dose of 1.0 c.c. of normal fluid does not yield positive reactions and that with these larger doses, cases of syphilitic infection of the central nervous system will be detected by the Wassermann reaction which would otherwise react negatively if 0.2 or 0.4 c.c. of fluid were used. I have used routinely for years in the method first described 0.8 c.c. of fluid, and in the second method graded doses up to 1.0 c.c. as described, with consistent and reliable results. In my opinion, a negative result should not be reported with a cerebrospinal fluid unless it has been tested in doses up to 0.8 c.c. at least.

LANGE'S COLLOIDAL GOLD REACTION

According to the exhaustive studies of Zsigmondy on metallic colloidal solutions, a solution of protein substances will precipitate a solution of colloidal gold in the absence of an electrolyte. An electrolyte, such as sodium chlorid, will in certain concentrations precipitate the colloidal gold itself; if proteins be present, this precipitation is inhibited. The degree of protection afforded has been found specific for each protein and is expressed in terms of milligrams of the protein capable of protecting 5 c.c. of colloidal gold against 0.5 c.c. of a 10 per cent solution of sodium chlorid.

Lange endeavored to distinguish between *normal* and *luetic* sera by this means as the basis of protein disturbances in syphilis, but failed; he then sought to measure the protein content of cerebrospinal fluid by the degree of precipitation of gold, but failed again, because he used distilled water as a diluent, thereby throwing the proteins—particularly the globulins—out of solution, and rendering them inert. When, however, he used a 0.4 per cent solution of sodium chlorid as a diluent, it was found that the proteins were not precipitated and that this amount of salt was too weak to precipitate the colloidal gold solution. It was now possible, according to Lange, to measure the protein content of spinal fluid according to the degree of precipitation, and very interesting and practical results have been secured although it cannot be stated as proved that the precipitation is due entirely to protein, particularly since it has been shown that the globulins may actually protect colloidal gold against pre-

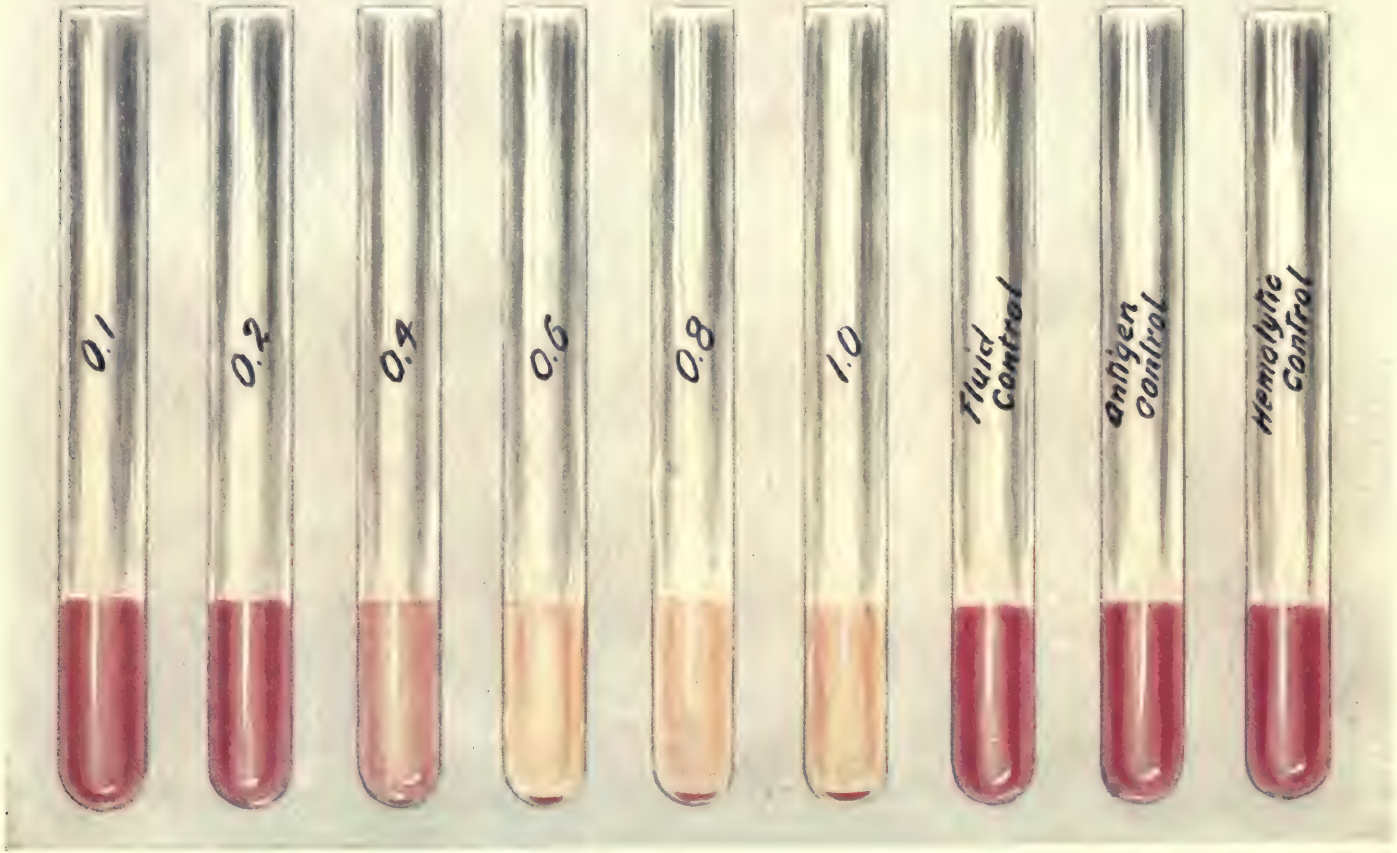

PLATE III.—THE WASSERMANN REACTION EMPLOYING GRADED AMOUNTS OF CEREBROSPINAL FLUID.

The tests with 0.1 and 0.2 c.c. of fluid were negative; the 0.4 c.c. dose yielded a moderately positive (+++) reaction while the higher doses yielded strongly positive (++++) reactions. The fluid control contained 1.0 c.c. fluid.

cipitation. Weston has shown that the reaction is not due to a peptone. Zaloziecki regards this as a form of immunity reaction; Jaeger and Goldstein consider it purely physical and probably of an electrical nature. Until the question is definitely settled it were well to place it among the protein reactions.

Preparation of Colloidal Gold Solution.—The preparation of a suitable solution of colloidal gold is frequently an exceedingly troublesome procedure and the success of the test depends upon a satisfactory solution. The method which I shall briefly describe here and which I have found to yield fairly constant and satisfactory results, is similar to that of Miller, Brush, Hammers and Felton.

The glassware (beakers, pipets and test tubes) must be absolutely clean. They may be washed in hot water with ivory soap; rinsed in tap water for five minutes; placed in a hot bichromate cleaner for half an hour; rinsed in tap and finally triply distilled water. The beakers should be used at once; the pipets and test tubes are to be dried in hot air oven. Thermometers should be cleansed in a similar manner.

It is necessary to use water *triply distilled* in an apparatus *free of rubber connections.*

1. Heat 1,000 c.c. of triply distilled water over a good Bunsen burner in a prepared beaker with a thermometer.

2. At 60° C. add 10 c.c. of a 1 per cent solution of Merck's gold chlorid crystals in triply distilled water and 7 c.c. of a 2 per cent solution of Merck's blue label potassium carbonate in triply distilled water.

3. At 80° C., while stirring briskly, add 10 drops of a 1 per cent solution of Merck's blue label oxalic acid crystals in triply distilled water.

4. At 90° C. remove the burner and while stirring add 5 c.c. of a solution consisting of 1 c.c. of Merck's highest purity formaldehyd in 40 c.c. of triply distilled water, or enough to produce an initial pink color.

5. The solution must be neutral in reaction, and for this purpose is tested with a 1 per cent solution of alizarin red in 50 per cent alcohol. With this indicator the neutral point is a brownish red tint; an acid solution gives a lemon-yellow and an alkaline solution a purplish-red color.

To 10 c.c. of the colloidal gold in a clean beaker add two drops of indicator. If it be acid, titrate to the neutral point with N/50 NaOH; if alkaline, titrate with N/50 HCl. After ascertaining the amount of N/50 NaOH or N/50 HCl required for 5 c.c., calculate the amount to be added for the amount of colloidal gold solution at hand.

Standards.—The following are suitable standards for a good colloidal gold solution:

(*a*) Absolutely transparent and of a brilliant red orange, or salmon red color.

(*b*) Five c.c. of the solution must be completely precipitated by 1.7 c.c. of a 1 per cent solution of sodium chlorid in one hour.

(*c*) The solution must be neutral in reaction when used.

(*d*) The solution must not produce a reaction greater than a No. 1, with a normal cerebrospinal fluid and must give a typical reaction curve with a known paretic fluid.

The Test.—1. Arrange 11 clean dry test tubes in a row; put 1.8 c.c. of *fresh, sterile 0.4 per cent NaCl solution* into the first tube and 1 c.c. into the following ten.

2. With a clean, dry pipet add 0.2 c.c. of *blood-free* fluid to the first tube and mix; transfer 1 c.c. from the first to the second tube. Mix and proceed in this manner up to and including the tenth tube, from which 1 c.c. is discarded. The eleventh tube is the control and contains no cerebrospinal fluid. The dilutions now range from 1-10 to 1-5,120.

3. Add to each tube 5 c.c. of colloidal gold solution; mix and stand aside at room temperature over night; the readings are made next day and recorded by numbers according to the following scheme:

5 = complete decolorization (water clear)
4 = pale blue
3 = blue
2 = lilac or purple
1 = red-blue
0 = no change.

Types of Reactions.—1. Normal fluid produces no changes at all, or at most a No. 1 change in the first tube of the series.

2. The typical reaction is observed in general paresis giving complete decolorization in the first four to eight tubes of the series with changes of color in most of the remaining ones (for example, 5 5 5 5 5 4 2 1 0 0) and constituting the "paretic curve." A similar curve is usually found in taboparesis (Plate IV).

3. The cerebrospinal fluids of tabetics usually give the "luetic zone" curve of a No. 4 intensity (for example, 4 4 4 5 5 4 2 0 0 0); decolorization is partial in the first two or three tubes, then becomes complete and gradually returns to normal through the balance of the series. These changes, however, are not constant or characteristic (Plate V).

4. The fluid in cerebrospinal syphilis usually yields weak reactions of the paretic zone type. In tertiary syphilis without symptoms referable to the central nervous system similar reactions are frequently observed.

5. Fluids from cases of purulent or tuberculous meningitis give reactions which are usually maximal in the higher dilutions, the "Verschiebung nach oben" of the Germans.

Practical Value of the Colloidal Gold Test.—The reports of a very large number of investigators including Lange, de Cruris and Frank, de Cruris and Eberhardt, Grulee and Moody, Eicke, Jaeger and Goldstein,

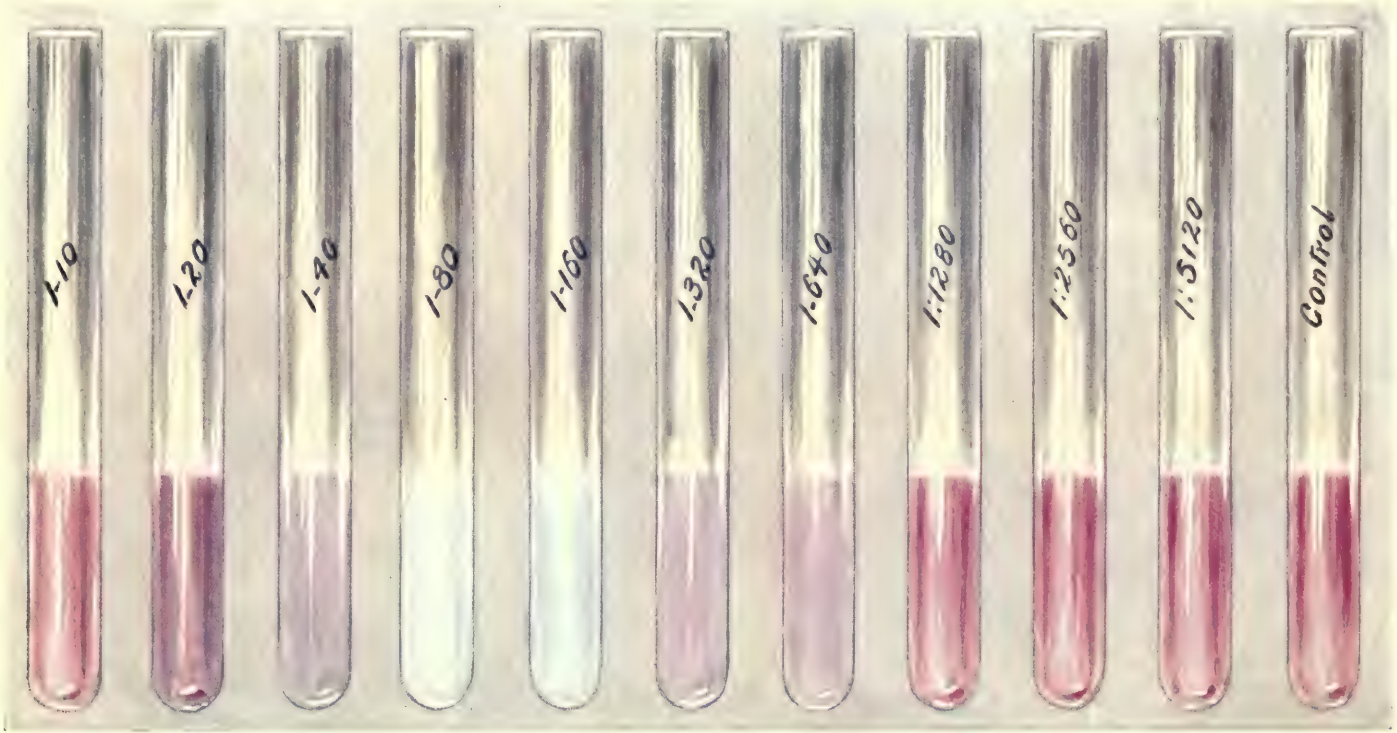

PLATE IV.—THE COLLOIDAL GOLD TEST, SHOWING THE REACTION WITH THE CEREBROSPINAL FLUID OF PARESIS ("PARETIC CURVE"). Complete decolorization occurred in the first four tubes with partial changes in the next four, yielding a 5 5 5 5 5 4 3 2 1 0 0 curve.

ERRATUM

The plate now facing page 200 is Plate V and should face page 202, while that facing page 202 is Plate IV and should face page 200. Descriptive matter of these two plates should be interchanged.

Klienberger, Zaloziecki, Kaplan, Miller and Levy, Swalm and Mann, Lee and Hinton, Weston, Darling and Newcomb, Solomon and Koefod, Miller, Brush, Hammers and Felton and others show that under proper condition the colloidal gold test is highly specific and of value in the diagnosis of general paresis. The reactions in tabes and cerebrospinal syphilis are not characteristic and at most may prove of value in confirming a doubtful diagnosis. A paretic reaction in a luetic individual should be regarded as grave, for while paresis may not be clinically distinct, the disease is likely to develop and intensive treatment is indicated in an attempt to arrest the disease.

BACTERIOLOGY OF THE CEREBROSPINAL FLUID

The normally cerebrospinal fluid is a poor culture medium; in inflammatory lesions of the meninges, however, the increase in protein and dextrose improves the cultural properties. A comparatively large number of pathogenic microörganisms may be found in the cerebrospinal fluid in disease, principally in the various forms of acute and chronic meningitis, of which mention may be made of the tubercle bacillus, Diplococcus intracellularis meningitidis, streptococcus, pneumococcus, staphylococcus and the influenza bacillus. Treponemata pallida have been demonstrated by Hofmann, von Dohio, Noguchi, Nichols and Hough, Wile, Sezary and Paillard, von Lewy and others by dark field illumination, the Levaditi stain and particularly by inoculation into the testes of rabbits. Trypanosoma gambiensa has been found in the fluid by Castellani and Bruce and others; other parasites are found very seldom; Cysticercus cellulosae has been found by Hartmann and actinomycosis by Sicard. The readily cultivated cocci at times recovered from the spinal fluid in acute poliomyelitis are regarded by most investigators as secondary invaders rather than the true etiological agent of the disease; at present I look upon these cocci as analogous to the relation of streptococci to scarlet fever.

Bacteria and other microparasites are found in fresh and stained smears of the sediment secured by centrifugalization and by cultural methods. If the fluid be turbid with cells and bacteria, direct smears may be stained with Loeffler's methylene blue and according to the method of Gram. Tubercle bacilli are particularly difficult to find. A large volume of the clear fluid may be centrifuged for an hour at high speed and smears prepared of the sediment, or, the fluid may be placed in a refrigerator over night and a portion of the fine fibrin coagulum that usually forms, teased out on glass slides. These are stained with hot carbolfuchsin for five minutes, washed in water, decolorized with acid alcohol or 15 per cent sulphuric acid, washed in water, counterstained with Loef-

fler's methylene blue, washed in water, dried and carefully examined (one hour's search may be necessary) with an oil immersion lens.

A portion of the sediment should be injected subcutaneously in the region of the inguinal lymph glands of young guinea-pigs and the animals observed for several weeks for evidence of tuberculosis.

If cultural methods be employed every effort should be made to collect the fluid under aseptic precautions and to prepare cultures with large amounts of fluid (*at least one c.c.*) *as soon after withdrawal as possible.*

As a general rule fresh human or rabbit blood dextrose agar tubes or plates are best suited for this work; Loeffler's blood serum may be used, but is less serviceable. Ordinary culture media as plain agar, gelatin, broth or milk are generally unsuitable, as the pneumococcus, influenza bacillus, meningococcus and others do not grow well on these media.

THE CEREBROSPINAL FLUID IN SPINAL DISEASES

Having reviewed in the preceding pages the general physical, chemical, cytological and serological properties of normal and pathological cerebrospinal fluid, I shall now consider the cerebrospinal fluid changes in certain diseases and particularly in spinal diseases. It is to be emphasized, however, that these changes are seldom pathognomonic, but rather of a general character, and the results of a laboratory examination must always be interpreted in conjunction with clinical observations.

With the cloudy or purulent fluid of acute meningitis in which the microörganisms are found by smear or culture, nothing more is necessary for diagnosis, although cell counts and protein determinations furnish data indicating the severity of the infection, and serve as guides, indicating regression or progression of the disease under treatment; in practically all other conditions more complete studies according to the following outline are advisable before the full value of a cerebrospinal fluid examination is to be appreciated (see chart, Fig. 86):

1. Pressure as taken with the Landon manometer and in a uniform manner, preferably, with the patient lying on the left side.
2. Physical appearance of the fluid.
3. Total cell counts made with fresh warm fluid and, preferably, with the Fuchs-Rosenthal chamber.
4. Differential cell counts made with direct smears of the sediment secured by thorough centrifugalization or by the Alzheimer method.
5. Protein determination, employing the Noguchi, Pandy, or Kaplan tests.
6. Sugar determinations, employing the simple and rather crude Fehling's reagent or the more accurate micromethod of Bang.

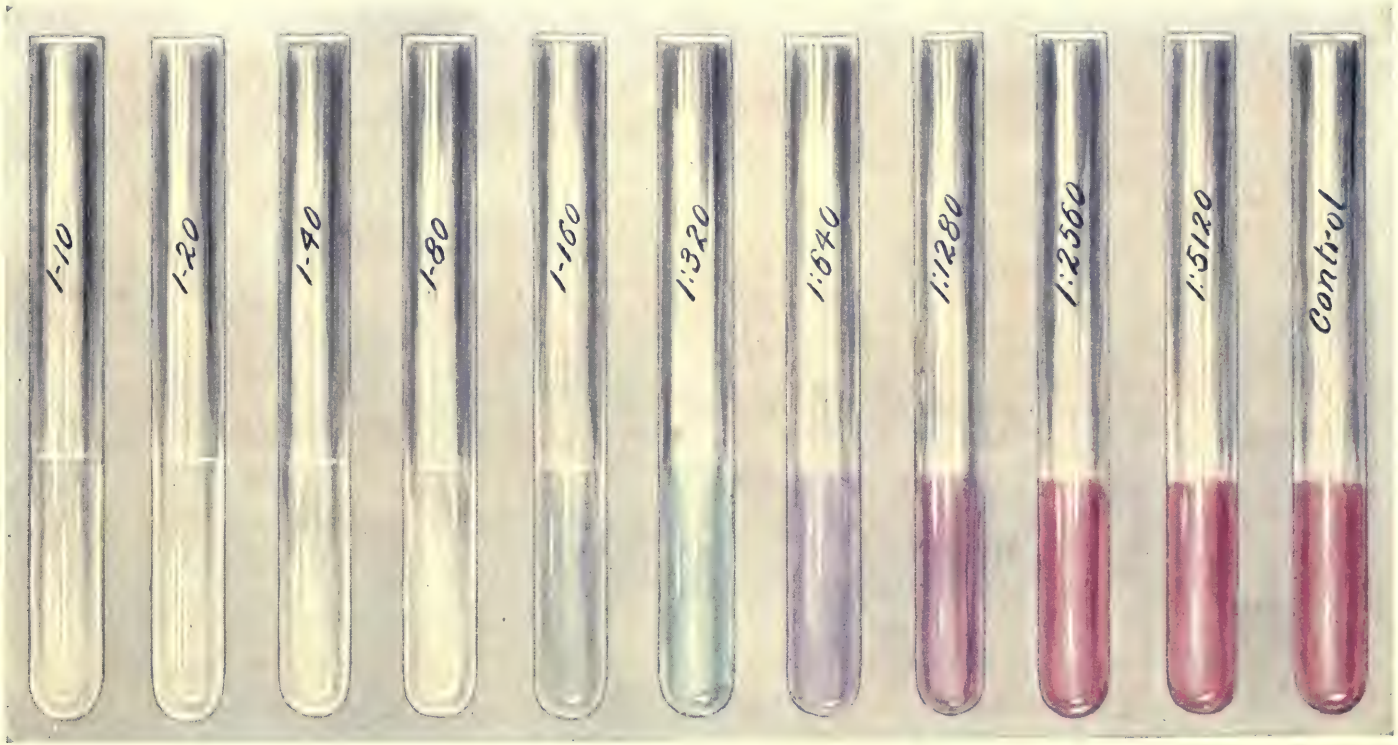

PLATE V.—THE COLLOIDAL GOLD TEST WITH THE CEREBROSPINAL FLUID OF TABES DORSALIS, SHOWING A "LUETIC ZONE" REACTION (0 1 2 5 5 2 2 0 0 0).

7. The Wassermann reaction, employing graded amounts of fluid up to and including a dose of at least 0.8 c.c.

8. The Lange colloidal gold test, employing an acceptable reagent.

9. Bacteriologic examinations if the presence of bacteria is suspected; by direct examination of stained smears of sediment or cultures of the fresh fluid or sediment on appropriate culture-media. Animal inoculation tests may be employed for the detection of tubercle bacilli and Treponema pallida.

As far as possible, I shall summarize the spinal fluid changes in disease from the standpoint of pressure, physical changes, protein content, reduction tests.

Tumors of the Spinal Cord.—Whether the spinal fluid shows changes in tumors of the spinal cord, depends largely upon the size and nature of the growth. The changes described are fairly constant but not characteristic of tumors of the cord, and tumors of the meninges or spinal column may bring about similar changes. Very small growths may produce no discernible changes in the fluid, but as a general rule compression of the cord leads, sooner or later, to passive congestion, to transudation and stasis of the spinal fluid, to massive coagulation and xanthochromia (*vide* p. 184) and usually to an increase in the cerebrospinal pressure.

In a typical case the fluid undergoes spontaneous coagulation within a few minutes or in several hours, due to an excess of fibrin ferment. The fluid contains a great excess of protein which is a characteristic feature; the clinical tests, such as Nonne's Phase I, Pandy's and Noguchi's reactions, are strongly positive. It has a characteristic yellow color due to the presence of blood pigment (xanthochromia), but may be colorless. Blood is usually absent, but may be present—particularly in sarcomata. Reducing substances are usually increased, but may be decreased, or even absent; the chlorids are commonly decreased. Hauptmann's saponin reaction is likely to be positive, due to increased amounts of cholesterin, and is especially valuable in the diagnosis of cholesteatomata.

The cells are not increased unless the meninges are irritated, when borderline or slightly higher counts are found. Tumor cells are seldom present. The absence of pleocytosis and the high protein content are the two most characteristic features. The blood and spinal fluid Wassermann reactions are usually negative unless the tumor is a gumma or the patient has an underlying syphilitic infection in addition to a tumor of the cord of a non-syphilitic nature.

Tumors of the Cauda Equina.—Tumors of the cauda equina are less likely to produce spinal fluid changes than tumors situated higher up in the cord. The difficulty of securing fluid from the immediate neighborhood of the new growth also diminishes the practical value of spinal fluid examination in these cases. In the comparatively few cases on record

where the spinal fluid has been examined the findings were either those of a normal fluid or, in large tumors, approached the changes characteristic of the syndrome of compression—namely, high protein content with little or no increase of cells.

Tumors of the Spinal Meninges.—Intramedullary or extramedullary tumors of the meninges produce a spinal fluid change characteristic of the "compression syndrome," namely, massive coagulation, xanthochromia, protein excess and absence of pleocytosis, as described above in tumors of the spinal cord. These changes are due to the passive congestion of the meningeal vessels with increased transudation of serum and stasis of the spinal fluid. Pressure is usually increased below the tumor. In cholesteatomata, crystals of cholesterin have been found in the fluid and Hauptmann's saponin reaction is likely to be positive. The blood and spinal fluid Wassermann reactions are usually negative unless the tumor is of syphilitic origin. The protein content is generally very high; the number of cells is normal or may show a mild pleocytosis.

Tumor cells are in most instances absent, but have been present and recognized as such. In sarcoma and carcinoma of the meninges characteristic cells may be found in the fluid. In sarcoma of the meninges numbers of large round cells with large nuclei resembling the sarcoma cells have been found; Schwartz has reported large endothelial cells in the fluid in cases of endothelioma of the meninges. Both sarcoma and endothelioma are likely to yield yellow or brownish colored fluids rich in protein.

Tumors of the Spinal Column.—Whether spinal fluid changes will be found in tumors of the spinal column depends upon the location and size of the tumor as determining the presence or absence of compression of the meninges and cord. Tumor of the spine itself or those adjacent to the spinal canal may produce an irritation of the meninges with increase of protein and cells. When sufficiently large to compress the meninges and cord the typical changes of compression will be found—namely, spontaneous coagulation, xanthochromia, excessive protein and mild pleocytosis.

Injuries to the Spinal Column and Cord.—Changes in the cerebrospinal fluid following injuries to the spine, as fracture, fracture-dislocation, dislocation, intervertebral disc injury, contusions and direct penetrating wounds (stab and gunshot) depend upon the degree of injury to the meninges and cord.

Hematorachis is the first and most characteristic and constant finding in the fluid when the vessels of the meninges or cord have been lacerated. During lumbar puncture, if a few drops of venous blood flows from the needle followed by spinal fluid, it is probable that a vein has been entered in the passage of the needle. If lumbar puncture is performed

within an hour of the time of injury, the spinal fluid is found to contain relatively large amounts of fresh blood that coagulates slowly and settles beneath a colorless or slightly yellowish fluid. Lumbar puncture several hours after injury may yield a dry tap, or at most a few cubic centimeters of yellowish fluid, due to intraspinal coagulation of the blood about the injured area.

In *sprains, dislocations, contusions and other injuries without actual laceration or injury to the arachnoid and pia mater* the cerebrospinal fluid shows practically no departure from the normal. Extradural hemorrhage may, in the course of a few days, result in giving the fluid a yellowish tinge, but blood cells are not to be found. On the first day of the injury, therefore, blood cells are present in a light yellow fluid; during the following weeks or ten days the erythrocytes rapidly disappear, unless bleeding continues at intervals and the fluid assumes a dark yellow to a reddish-yellow color due to blood coloring matter, gradually returning to its normal colorless condition. Soon after the injury the leukocytes present in the fluid (small lymphocytes, polymorphonuclear neutrophils and eosinophils) are derived from the blood; after the first week the number of polymorphonuclears decreases while the number of small lymphocytes and endothelial cells increases, due probably to the irritative meningitis and the reparative process at the site of the injury. During the first few days the fluid contains an excess of protein due to the serum of the blood; later the protein content varies considerably according to the degree of meningitis and may be normal. In severe injuries accompanied by well-marked secondary inflammatory changes, the products may produce compression of the cord, the fluid containing large amounts of protein, a few cells, and having a yellowish color (xanthochromia haemorrhagica). During the first few days after injury the amount of sodium chlorid is decreased or normal and the dextrose content slightly increased.

Hematomyelia may accompany severe contusions and meningeal hemorrhage or occur in the cavity of syringomyelia. Small hemorrhages in the cord without involvement of the meninges produce no discernible changes in the spinal fluid. If syphilis be present, the fluid and blood Wassermann reactions may be positive; this may have a general etiological relationship to hematomyelia by blood vessel and general tissue changes.

Syringomyelia.—In syringomyelia the cerebrospinal fluid may show no changes unless meningeal irritation is present, when an excess of protein may be found. The Wassermann reaction may or may not be positive, as syphilis bears no direct etiological relationship to the cord lesions. The cells are usually normal in number; Fehling's solution is reduced and the chlorid content is unchanged.

Meningitis.—Acute Meningitis.—Voisin divides the course of an

acute meningitis into four phases, which I shall give here because of their importance in relation to the changes in the cerebrospinal fluid:

1. Stage of Congestion: protein and cells normal; sugar increased.
2. Stage of Serous Exudate: protein and cells normal or slightly increased; chlorids decreased.
3. Stage of Serous Edema: protein slightly increased; increased number of small lymphocytes; sugar slightly increased; chlorids markedly diminished.
4. Stage of Purulent Exudate: protein markedly increased; cells markedly increased; sugar decreased or absent; chlorids decreased.

Acute Meningeal Congestion.—Serous Meningitis.—In a typical case the cerebrospinal fluid shows the following changes: the pressure is increased and the fluid may flow rapidly from the lumbar puncture needle. It is clear, limpid, and resembles normal fluid. The protein content is unchanged and the clinical globulin tests are negative; later traces of protein may be found. The sugar content is normal or slightly increased (Fehling's solution is reduced), and the total cell count is usually borderline (about 12-15 cells per c.mm.) or slightly higher. Smears of the sediment of the centrifuged fluids and cultures are negative for bacteria.

Localized Infectious Meningitis.—The changes in the cerebrospinal fluid vary with the degree of meningeal involvement and correspond to the findings of diffuse meningitis. The pressure is usually increased; the fluid is excessive in amount, opalescent or slightly turbid. The protein is increased, the globulin tests positive, the sugar decreased or entirely absent (Fehling's test negative) and the chlorids generally diminished. The total cell count is likely to be high, owing to the presence of polynuclears and lymphocytes, and smears and cultures usually disclose the infecting microörganism.

Purulent Meningitis.—The pressure is usually increased; during the early stages the flow of fluid is likely to be brisk. Later, and especially if the fluid is purulent and viscid, the flow is quite slow or ceases altogether. The fluid, cloudy and turbid, is usually whitish-yellow, but may become yellowish- or greenish-brown, due to the presence of blood and bacterial pigments. There is a great excess of protein; the clinical globulin tests are strongly positive. The chlorids and sugar are greatly reduced, the latter at times being entirely absent. The total cell counts are very high and stained smears show a great excess of polymorphonuclear pus cells. The infecting microörganism, as the meningococcus, pneumococcus, streptococcus or other microörganism, will be detected in the smears or from culture studies.

Tuberculous Meningitis.—The pressure is increased; the fluid, excessive in amount, usually flows quite rapidly from the needle; it is generally colorless and otherwise normal in appearance, although it may have a

slightly yellowish tinge—particularly in the later stages. A fibrin coagulum usually develops upon standing, due to an excess of fibrinogen and fibrin ferment. The protein is increased; in infants the total protein may reach 0.1 to 0.2 per cent, in adults 0.2 to 0.3 per cent. The globulin tests are strongly positive and albumoses and peptones may be present. The chlorids and sugar are decreased; reduction of Fehling's solution may be very slight or absent. The total cell count is high, ranging from 15 to 300 cells or more per c.mm. of fluid. Small lymphocytes predominate, especially in the subacute and chronic stages. During the early and acute stages many polymorphonuclears and endothelial cells are present. In many instances smears of the sediment or of the fibrin coagulum reveal the tubercle bacilli, although prolonged search is usually necessary, and animal inoculation tests may be positive.

Hemorrhagic Pachymeningitis.—External hemorrhagic pachymeningitis produces no changes in the cerebrospinal fluid, but the internal variety is frequently found in syphilis (paralytic dementia) and chronic alcoholism. The hemorrhage may be spontaneous or due to trauma. The pressure is either normal or slightly increased, the fluid either water clear or a light yellow or hemoglobin color. According to Quincke the blood-coloring matter may reach the fluid by diffusion, the hemorrhage itself not being in direct contact with the subarachnoid space. The protein is likely to be slightly increased and the globulin tests positive. The sugar content is normal, the chlorids and cell count are normal or slightly increased, both lymphocytes and polymorphonuclears being found. In case of infection of the clot the character of the fluid changes to that described under circumscribed purulent meningitis, and bacteria are found in the fluid.

Subacute and Chronic Meningitis.—In the subsiding stages of those cases of meningitis from which the patients recover, the cerebrospinal fluid undergoes certain changes. The pressure gradually returns to normal. In case inspissation of pus takes place in the spinal canal it is impossible to measure pressure, as the fluid flows either very slowly or not at all. As pus and bacteria decrease the fluid becomes clearer. The protein content remains slightly increased until recovery is practically complete, and the sugar content is gradually restored as the bacteria disappear. The total cell count continues above normal, though gradually decreasing, and the polymorphonuclears are the first to disappear. In the chronic meningitis of alcoholism, plumbism, senile dementia and acquired and hereditary syphilis the pressure is slightly increased; the globulin tests are faintly positive; the chlorids and sugar are normal or slightly increased, as is also the total cell count, owing to the presence of small lymphocytes.

In hypertrophic cervical pachymeningitis the cerebrospinal fluid usu-

ally exhibits the changes just described under chronic meningitis, and in addition there may be a "luetic zone" colloidal gold reaction and a positive Wassermann reaction with both fluid and blood. *Spinal pachymeningitis* is usually due to caries of the vertebrae, malignant tumors or injuries; in a well-marked case the cerebrospinal fluid shows the typical changes of the Froin syndrome—namely, spontaneous coagulation, great excess of protein, a yellow color and few cells.

Myelitis and Meningomyelitis.—Whether changes in the cerebrospinal fluid be found in myelitis depends largely upon the etiology. In acute myelitis of the transverse or disseminated variety and in acute encephalitis, both without involvement of the meninges, the cerebrospinal fluid shows no abnormalities. In pure myelitis or encephalitis accompanying an infectious disease the fluid shows no changes from the normal, except possibly a slight increase in the sugar and sodium chlorid content ascribed to co-existing congestion of the meninges. There is no increase of protein and the cell count is normal. In meningomyelitis, however, the cerebrospinal fluid usually shows some changes and these may even reach an extreme degree. The pressure of the fluid is likely to be increased; depending upon the severity of the accompanying meningitis there is an increase of protein and an increase in total cells. The fluid may have a yellowish tinge resembling the fluid of xanthochromia and massive coagulation. In other words the fluid in meningomyelitis shows the same kind of changes encountered in circumscribed and diffuse infectious meningitis; the degree of the changes from normal depends upon the extent of meningeal involvement.

Acute Anterior Poliomyelitis.—The fluid is generally clear or may show a faint opalescence, the pressure being moderately increased. The protein content is generally increased, the globulin tests weakly or moderately positive especially in the later stages and the sugar content is normal or slightly decreased. Complement-fixation tests for the purpose of detecting antibodies and poliomyelitis antigen in the fluid have been usually negative in the experiments of Gay and Lucas, Wollstein, Kolmer and Freese, and Römer and Joseph; Schottmüller found the fluids in two out of four cases to yield positive Wassermann reactions.

The cells are generally moderately increased in number even in the earliest stages, so that a total cell count is of greatest value in the laboratory diagnosis of this disease. Gay and Lucas found a marked increase of cells during the incubation and prodromal stages of experimental poliomyelitis of monkeys. Peabody, Draper and Dochez divide the cases into two main groups on the basis of a high or low cell count. Forbes, Abramson, Morse, Kolmer and others found an increase of cells in the majority of their cases. Early in the disease many polymorphonuclear cells may be found in the fluid, but generally speaking small lymphocytes are pres-

ent throughout. Colloidal gold reactions of the meningitic zone type are helpful in diagnosis.

Herpes Zoster.—After the theory of Head, herpes zoster is frequently designated in the German school as "poliomyelitis posterior acuta." The main change in the cerebrospinal fluid consists in a moderate increase of cells (50-60 cells per c.mm. according to Plaut, Rehm and Schottmüller) mostly of the large lymphocyte variety. Even after the clinical evidences of the disease have disappeared this increase of cells in the fluid is likely to persist for some time.

Tuberculosis Spondylitis.—Changes in the spinal fluid are entirely dependent upon the location and extent of the lesion and are likely to be present only when the meninges are involved. The condition of the fluid depends upon the degree of involvement, ranging from a perfectly normal fluid or a mild protein excess and slight increase of cells to the excessive changes of the compression syndrome (massive coagulation, xanthochromia, protein excess and mild pleocytosis). Small lymphocytes are especially likely to be found and tubercle bacilli in advanced, and, particularly, in open lesions.

Traumatic Spondylitis.—In trauma of the vertebrae and intervertebral cartilages the same principles are operative—namely, changes in the fluid are dependent upon the degree of involvement of the meninges and the compression of the spinal canal by the injury, hemorrhage and inflammatory products. In severe injuries the evidence of meningeal irritation may be found within twenty-four hours and if the meningeal vessels rupture, blood will appear in the fluid. Subsequently inflammatory changes about the injury, involving the meninges, cause a slight protein excess.

Syphilis of the Central Nervous System.—Examination of the cerebrospinal fluid has proven of value in the diagnosis and differential diagnosis of tabes, paresis and cerebrospinal syphilis. While in the earliest stages these diseases cannot be distinguished from one another by an examination of the fluid, later on definite changes occur, which are more of a general than of a specific character. Space does not permit a full discussion of these changes, but those found in what may be termed "typical" cases are presented with emphasis upon the many possible variations.

The cerebrospinal fluid changes in *tabes dorsalis,* which is now generally considered as being caused by the Treponema pallidum, vary according to the severity and stage of the disease. The pressure is usually increased, particularly during crises or other acute stages. The fluid is generally water clear and normal in appearance; fibrin coagula seldom develop. The protein content is within normal limits or slightly increased. In the usual type of tabes, the globulin tests are generally posi-

tive (90-95 per cent). The sugar content is normal or may show a slight decrease when measured by quantitative methods. Fehling's solution is always reduced. The chlorids are usually normal. Traces of cholin and phosphoric acid may be present.

The total cell count is generally above normal. In the usual type of the disease Kaplan found the cells between 37 and 73 per c.mm.; he described a hyperlymphocytic type of tabes in which the cells vary from 100 to 300 per c.mm. In general terms an increased cell count may be expected in 85 to 95 per cent of cases of tabes dorsalis; in about 7 per cent of cases the cell counts fall within normal limits and the globulin and Wassermann tests are likewise negative. Of the cells present, over 90 per cent are of the small lymphocyte variety; occasionally, and particularly during a crisis, many polymorphonuclear cells may be present.

The cerebrospinal fluid Wassermann reaction is positive in from 21 to 60 per cent of cases; with Hauptmann's technic, which employs large doses of fluid, the Wassermann test yields a higher percentage of positive reactions (about 87 per cent). Lange's colloidal gold test usually shows a "luetic zone" type of reaction; there is no definite or diagnostic reaction in tabes as in paresis.

In cases of *taboparesis,* before the cerebral symptoms develop, the persistently positive Wassermann reactions with blood and fluid—and particularly the former—despite vigorous treatment, are of great importance. The tabetic showing this "Wassermann-fast" quality of his blood or fluid, or both, should be carefully observed for evidences of general paresis.

The cerebrospinal fluid changes in *paresis* are usually very pronounced and definite. The pressure is increased especially during the more acute stages. The fluid is generally water-clear and normal in appearance, though small flakes of fibrin may form after standing, especially when there is present a large amount of protein. The protein content is increased; the globulin tests are practically always positive. The amounts of albumin and globulin depend upon the severity of the disease. The sugar content is normal or slightly decreased, Fehling's solution being generally reduced, the chlorid content generally normal, and traces of cholin are found with other disintegration products of nerve and brain tissue.

The cells are increased in at least 98 per cent of cases—usually 30 to 100 cells being found per c.mm. of fluid, although the total number may reach 200 or more per c.mm. The majority of the cells are small lymphocytes, but plasma cells and large lymphocytes may also be found. The Wassermann reaction with blood and serum and cerebrospinal fluid is positive in from 97 to 100 per cent of cases and is characterized by its strongly positive nature and the difficulty with which it is influenced by

vigorous treatment. Lange's colloidal gold test usually yields a typical paretic reaction and is of considerable value in the diagnosis of this disease.

The fluid changes in *cerebrospinal syphilis* vary according to the location of the infection—that is, whether the disease be purely spinal or cerebral or a combination of both, and whether it be of a purely meningeal, gummatous or endarteritic variety.

In the *meningeal form,* which includes about 33.3 per cent of cases (Kaplan), the fluid changes are somewhat comparable to those of other forms of meningitis, particularly that of tuberculous origin. The pressure is increased; the fluid is usually clear, but fibrin coagula may form on standing; the protein content is usually increased and the globulin tests positive in at least 50 per cent of cases; the sugar content is frequently decreased and Fehling's test may be negative; the total cell count is always high, ranging from 18 to 1,000 cells per c.mm.; the majority of the cells are of the lymphocytic variety, but many polymorphonuclear cells are not infrequently present; the fluid Wassermann test is positive in about 100 per cent and the blood Wassermann positive in about 90 per cent of cases. The colloidal gold test does not yield a specific reaction; in the majority of cases a "luetic zone" reaction is observed.

In the *gummatous form* of cerebrospinal syphilis the fluid changes resemble those described, but vary greatly according to the extent of meningeal involvement.

In the *endarteritic type*—a much rarer form of this disease—the cells and the protein content are normal or but slightly increased, while the globulin tests are usually negative. Fehling's solution is promptly reduced, and the fluid and blood Wassermann reactions in most instances positive.

In the *Plaut* or *negative Wassermann reaction* type of this disease (about 58 per cent of Kaplan's cases) the fluid changes are quite similar to those described above in the meningeal form, except that the Wassermann reaction with the fluid is generally negative. An excess of protein is usually present; likewise Fehling's solution may be reduced; the pleocytosis is marked, varying from 100 to 1,400 cells per c.mm. of fluid; the blood Wassermann is positive in about 90 per cent of cases. The distinctive feature, however, is the negative Wassermann reaction with a fluid showing the changes of meningeal irritation or meningitis. In the transition of cerebrospinal syphilis to general paresis the persistence of a high cell count and positive blood and fluid Wassermann reactions despite vigorous treatment are of chief import.

Multiple Sclerosis.—In multiple sclerosis the cerebrospinal fluid pressure is normal, or it may be slightly increased in the severer cases; the fluid is water clear; the protein content has been found generally nor-

mal, although Nonne and Holzmann report weakly positive Phase I reactions in 17 per cent of their cases. Kaplan in 16 cases did not find the globulin in excess; Henkel in 9 cases found 5 showing a slight excess.

A mild pleocytosis has been found in 25 per cent of cases, due mainly to the presence of small lymphocytes and a few larger cells—presumably the lining endothelial cells. In the majority of cases the cell count is normal, or at most borderline (Kaplan). The Wassermann reaction is negative unless syphilis be present, though Kaplan found three cases and Eichelberg two with positive fluid reactions. DeCrini and Eberhardt have observed the "luetic curve" in the colloidal gold test with the spinal fluids of four cases.

Spinal Spastic Paralysis.—In the majority of cases of spinal spastic paralysis the cerebrospinal fluid shows no changes. Plaut, Rehm and Schottmüller state that in a small percentage of cases a slight excess of protein with mild pleocytosis may be found. The Wassermann reaction with blood and fluid is generally negative, though both have been found positive in lateral sclerosis of syphilitic origin.

Congenital Spastic Paralysis (Little's Disease).—In these cases the cerebrospinal fluid presents no abnormalities. Kaplan has found no changes in six cases. Plaut, Rehm and Schottmüller report a slight increase in lymphocytes. The Wassermann reaction may be positive and should always be conducted with the blood and also with the fluid, if this can be secured.

CEREBROSPINAL FLUID EXAMINATION AS A GUIDE IN TREATMENT

The examination of the cerebrospinal fluid has a great field of usefulness as a guide to the efficacy of treatment being an indication of the progress of the disease.

In *epidemic cerebrospinal meningitis* treated with intraspinal injections of antimeningococcic serum, the dosage is guided not only by the clinical condition of the patient but also by the appearance of the fluid; clearing of the fluid with a decrease of polymorphonuclear pus cells and meningococci and the increasing tendency of the cocci to occur intracellularly are of good import. It is well in this connection to bear in mind that the serum itself may produce meningeal irritation responsible for the presence of polymorphonuclear cells.

In *tabes, paresis* and *cerebrospinal syphilis* receiving treatment with mercury or with salvarsan by intravenous or intraspinal injections, or both, the influence exerted upon the total cell count, protein content, blood and fluid Wassermann reactions and probably also upon Lange's colloidal

gold test, serve as delicate indicators of the condition of the patient. The cells are usually first reduced; then the protein content diminishes; the conditions of the fluid and blood responsible for the positive Wassermann reactions are most difficult to influence and these are the last to disappear as cure is effected. In this manner Nonne's "Four Reactions" serve the physician as delicate indices of the patient's condition and progress.

After the intraspinal injection of novocain or other compounds for the production of *spinal anesthesia* a slight irritation of the meninges may follow with a moderately increased cell count as the chief change in the fluid.

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CHAPTER IV

THE ROENTGEN EXAMINATION OF THE SPINE

HENRY K. PANCOAST

The roentgen examination of the spine is confined solely to the bony structure of the vertebrae and the intervertebral articulations, and here, as elsewhere in bones and joints, this is a recognized routine means of diagnosis in connection with diseases and injuries of the osseous and articular structures, congenital anomalies and deformities. So far, no direct knowledge has been obtainable in diseases and injuries of the cord or its membranes, and it is not likely that success in this direction will ever be achieved.

Accuracy in diagnosis implies correct technic and interpretation. The former plays a more important rôle than the average individual realizes. In a few words, it comprises such procedures as will furnish a maximum detail of all the structures and a minimum of distortion. The gross anatomical structure of the vertebrae is very complex as compared with most other bones, and the shadows of the various portions, occupying many planes, must be thrown upon the single plane of the roentgenogram. Sharpness of definition is, therefore, very important. The stereoroentgenographic method is frequently the only means of differentiating the shadows of the various parts of the complex vertebra.

There are many obstacles in the way of obtaining clear detail. Throughout most of the length of the spine, the vertebrae are located some distance from the skin surface, and in the thorax and abdomen the bodies occupy practically the middle of the anteroposterior plane of body, and the further a structure is from the plate, the less clear will be the detail of its shadow. Many portions of the spine have in front of them other structures of considerable density. In the upper cervical region, the lower jaw interferes with the anteroposterior view. The thoracic spine has in front of it the sternum, heart and aorta, all of which cast rather dense shadows. In the lateral view of this region the ribs on each side greatly interfere.

With the exception of the cervical region, the easiest procedure is an examinaton made in the anteroposterior direction, but even this may fail entirely in showing the particular portions of the vertebrae desired. Many injuries and their extent, as well as the amount of destruction of the bodies and the exact deformity resulting in tuberculous disease, can

be determined by the lateral view only. It is exceedingly difficult to obtain satisfactory lateral roentgenograms in many localities, as in the upper thoracic, lower lumbar and sacral regions, and the lumbar region in stout individuals. When neither of these views is entirely satisfactory, stereoroentgenograms may give the information desired by showing the

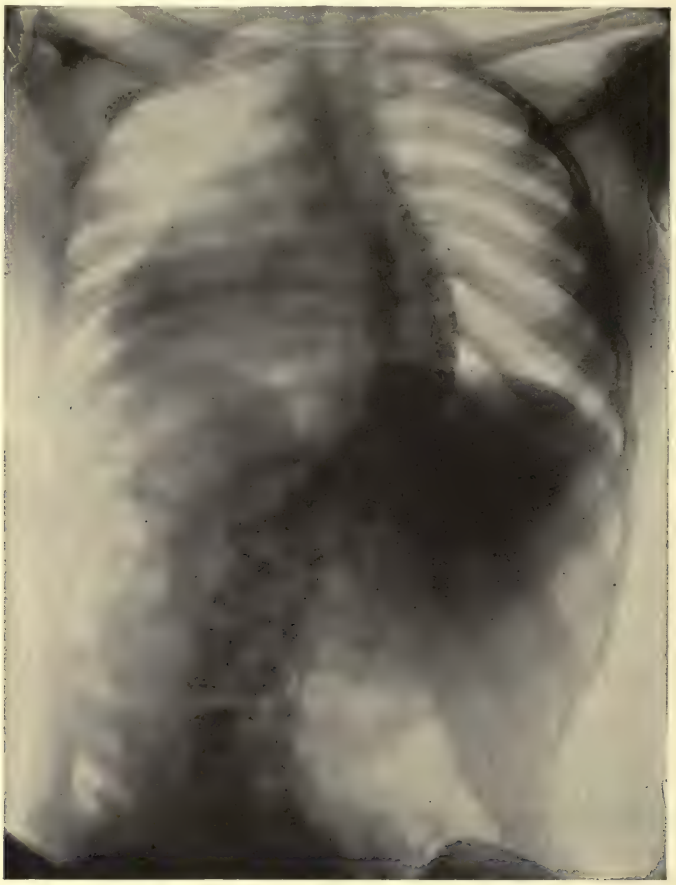

FIG. 87.—CASE OF EXTREME SCOLIOSIS, FEMALE, AGED 16 YEARS, SHOWING GROSS LATERAL DEFORMITY AND ROTATION OF VERTEBRAE.
The exposure was made from a distance to reduce distortion to a minimum.

area in perspective. In young children, who cannot be made to stop breathing, the moving ribs make lateral views of the thoracic region unsatisfactory unless the exposures be extremely rapid.

One of the most common faults in technic is the disregard of distortion. It is an all too common practice to include too many vertebrae in one exposure, and not infrequently the attempt is made to diagnose conditions when the entire spine has been included on a single plate. The

only service such a roentgenogram can render is to show the gross lateral deformity in a case of scoliosis (Fig. 87). It is impossible to show more than two vertebrae with the intervening space occupied by the disk without some distortion, especially in the lumbar region (Fig. 88). The more we attempt to include beyond this limit, the more oblique will be the rays, and the greater the distortion and the overlapping of the bodies, and the less reliable will be the plate in demonstrating the width of the intervertebral spaces. It is seldom practicable, however, to examine the entire

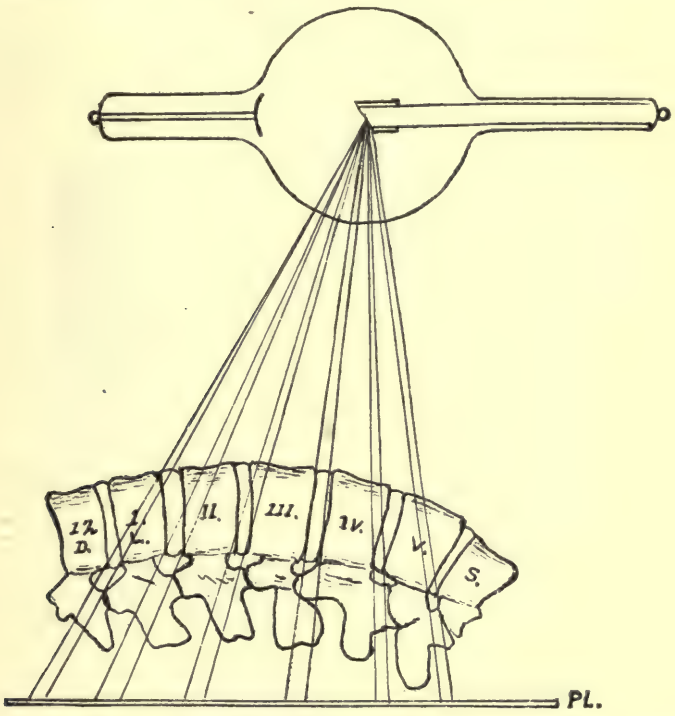

FIG. 88.—DIAGRAM ILLUSTRATING THE AMOUNT OF DISTORTION OF SHADOWS THAT WILL RESULT BEYOND THE TWO VERTEBRAE DIRECTLY BELOW THE TUBE TARGET. The only clear interspace will be that between the third and fourth lumbars.

spine with but two vertebrae included in each exposure, but certainly not more than three should be included in the lower thoracic and lumbar regions if distortion be in the least way disadvantageous.

Correct interpretation requires not only a knowledge of all anatomical details of the vertebrae but also a familiarity with characteristic appearances of pathological processes as depicted in the roentgenogram. The spine is still a field for further study and in many instances diagnoses are not self-evident, but must be expressed as opinions based upon considerable experience. A clinical knowledge of the patient's condition is often essential. For example, the appearance of metastatic carcinoma frequently

resembles that of tuberculous caries, and the correct interpretation must depend upon a knowledge of the presence of a primary neoplasm elsewhere; syphilitic osteomyelitis and sarcoma often present similar appearances, but with a history of syphilis or with a positive Wassermann reaction the evidence would be in favor of a luetic lesion.

TOPOGRAPHY

Cervical Region.—The anteroposterior view of this portion is usually unsatisfactory. The upper two or three vertebrae are overshadowed by the lower jaw and the base of the skull, but with care a satisfactory view may be obtained if the head be placed at the correct angle and the mouth

FIG. 89.—ANTEROPOSTERIOR VIEW OF THE UPPER TWO CERVICAL VERTEBRAE TAKEN THROUGH THE WIDELY OPENED MOUTH.

Showing the articulations between the atlas and the condyles of the occipital bone and between the atlas and axis. The odontoid process of the axis is very clearly shown.

held wide open by a large cork or other transparent body (Fig. 89). This view shows the bodies of the upper two or three vertebrae to good advantage and also the odontoid process of the axis, the condyles of the occipital bone and the intervertebral articulations between the first and second vertebrae. The transverse processes of the cervical vertebrae are

unusually large and wide and the bodies are relatively narrow, so that the anteroposterior view gives a false impression of width of the bodies. Moreover, the body comprises a relatively small part of the entire vertebra, and the superimposed shadows are comparatively greater than elsewhere in the spine, making it extremely difficult to interpret correctly all the shadows in this view. The anterior part of the lower edge of the body projects downward and its shadow overlaps the intervertebral space be-

FIG. 90.—LATERAL VIEW OF CERVICAL REGION, SHOWING ALL THE VERTEBRAE OF THIS PORTION.

The bodies, spinous processes, laminae and intervertebral articulations are best shown in this direction. Note the downward projection of the anterior part of the lower edge of each vertebra, which tends to obscure the intervertebral space in the opposite view.

tween it and the body below (Fig. 90). With the exception of the articulations between the occipital bone and the atlas and between the atlas and the axis, which are almost in a horizontal plane, the articular facets are in a plane extending from above downward and before backward, so that outlines of joint surfaces cannot be demonstrated in this view.

The lateral view is the more important in this region (Fig. 90). It shows all of the bodies of the cervical vertebrae down to at least the sixth and often including the seventh, depending largely upon the muscular development of the neck and shoulders and the amount of subcutaneous fat. The ring-like form of the atlas and odontoid process of the axis can be

well depicted. As there are no structures to interfere, the spinous processes and laminæ stand out prominently. The larger portion of the bony wall of the spinal canal is readily shown, and any encroachment upon the latter can be demonstrated to better advantage here than in any other region. The intervertebral joints occupy the outermost portions of the laminæ, and are in such a plane as to be seen to best advantage in this view.

FIG. 91.—OBLIQUE VIEW OF A PORTION OF THE THORACIC REGION.

Made at such an angle as to show the bodies and intervertebral spaces to good advantage and also the transverse processes on one side. The shadows of the overlying sternum, heart and vessels have been thrown out of range.

Thoracic Region.—This is the most unsatisfactory portion to examine in either view. In the anteroposterior direction, the shadows of the sternum, heart and vessels obscure the details to a considerable extent, and greater penetration and longer exposure are required than for the usual examinations of the chest. Oblique views at any angle between the anteroposterior and lateral are not satisfactory on account of the resulting distortion, although the more nearly they approach the lateral direction the better are the bodies shown (Fig. 91). In the anteroposterior

view the transverse processes are partly obscured by the origins of the ribs. As they are narrower and much shorter in proportion to the width of the bodies than is the case in the cervical region, a more correct impression of the size of the bodies is conveyed. Stereoscopic roentgenograms may be more readily interpreted than single plates in obscure cases of caries or growths. If it be necessary to show the entire thoracic spine in one exposure, it may be found advantageous to use a long narrow diaphragm. The intervertebral articulations are for the most part in a perpendicular lateral plane and are not well shown in the anteroposterior direction, but the facets for the articulations of the ribs face more directly outward, so that their joints can be observed to better advantage. The shadow of the thickest portion or tip of the spinous process can be seen through that of the body, but it should be borne in mind that this portion of the process is behind the body of the vertebra from which it springs only in the upper and lower thoracic regions, whereas in the mid-thoracic region, it is behind the body of the vertebra immediately below.

The lateral view would be the ideal one in this region were it not for the interference of the rib shadows on both sides, especially as the ribs are closest together and present their greatest curves near the spine. The laminae are almost completely hidden by them. Satisfactory lateral views are most difficult in the lower thoracic region where there is such a great contrast between the comparatively transparent lung structure and the much denser structures beneath the diaphragm. When circumstances permit of fairly clear lateral roentgenograms, the bodies are shown to far better advantage than in the anteroposterior direction.

Lumbar Region.—Anteroposterior views are far more satisfactory in the lumbar region than elsewhere. The bodies are much larger in comparison with the other portions of these vertebrae, the shadows of which are less confusing than in the cervical and thoracic spine. The body of the fifth lumbar is somewhat thicker in front than behind and it has a slant downward from behind so that a part of the sacral body is above the horizontal level of the lower border of the body of this vertebra. This prevents the space between the two bones from being clearly shown and makes the anteroposterior view of the fifth lumbar somewhat confusing. The intervertebral spaces are wide and with the transparent disks permit of a fairly clear view of the laminae, which project downward, between the bodies. Likewise, the intervertebral joints are frequently on a level with the disks, and as the articular surfaces are nearly in an anteroposterior plane the entire joint line is usually visible (Fig. 92). These joints can be more adequately studied in this region than elsewhere, and slight displacements and the lesions of chronic arthritis can frequently be detected. The transverse processes are of course readily seen, and their tips, often thick, cast much denser shadows than the other portions and occasionally may be so dense as to be confused with ureteral calculi. The

spinous processes project nearly straight backward, and the shadow, representing the thickest anteroposterior portion, usually corresponds to the body from which the process springs. For all examinations of the lumbar spine, the stomach and intestinal tract should be as nearly empty as possible.

The lateral view, if the individual is not too stout, is the more satis-

FIG. 92.—ANTEROPOSTERIOR VIEW OF LUMBAR SPINE OF ADULT MALE, DEMONSTRATING THAT ONLY TWO VERTEBRAE CAN BE EXPOSED AT CLOSE RANGE WITHOUT DISTORTION AND OVERLAPPING OF THE BODIES UPON THE INTERVERTEBRAL SPACES.

These spaces are wide in this region and readily permit an unobstructed view of a large portion of the laminae and the intervertebral articulations.

factory for studying the bodies of the lumbar vertebrae, as they stand out so conspicuously. Certainly the extent of the lesion and the resulting kyphotic deformity in tuberculous disease are better demonstrated in this view, as are also fractures of the bodies and the deformities in fracture-dislocations. The laminae may in some instances be better shown than in the other view, but the spinous processes can always be better seen laterally.

Sacrum.—This bone as a whole is readily shown in the anteroposterior

view, though satisfactory lateral views can be obtained in children and very thin adults. The lumbosacral and sacro-iliac joints are of special interest in their connection with many conditions. The sacral articular facets of the former face somewhat backward and inward, and, while the entire articulation cannot be so well shown as the intervertebral joints above, the line is usually distinct, a fact which is of advantage, partly because of the importance of this joint in arthritis, but more particularly because of the prevalence of slight displacements, which may be traumatic, or from which a scoliosis may seem to originate.

In the anteroposterior view the definition of the sacro-iliac joint depends largely upon the thickness of the articular cartilage, which is much wider in children. The anterior aspect is usually well-defined unless the cartilage be absorbed or the joint ankylosed. In order to show each joint to best advantage the rays should be directed from each side of the midline in the general direction of the articulation, taking each one separately. It is useless to attempt to interpret slight displacements of these joints without stereoscopic plates. Relaxation cannot be determined unless there be some displacement.

Coccyx.—Because of its small size and lack of density, compared with the overlying parts, it is often very difficult to show the coccyx satisfactorily. The presence of gas in the rectum or inflating with air may assist materially in increasing detail. Most of the so-called fractures are in reality disjunctions and can usually be diagnosed with more certainty by palpation than by roentgen examination. If *united,* the roentgen diagnosis is very uncertain because inequalities and distortions are often seen in the normal subject.

FRACTURES

From the roentgenological standpoint fractures may be most conveniently grouped on an anatomical basis. Fractures of the spinous processes are more common in the cervical region and fortunately are readily detected because at this level lateral views are easily obtained (Fig. 93). In the thoracic region the diagnosis is very uncertain because in this view the ribs on each side with their double curves overshadow the spinous processes to such an extent. Occasionally an anteroposterior roentgenogram will show the tip of a much displaced spine out of its proper position. In the lumbar region, where satisfactory side views are frequently possible, the diagnosis is not so difficult. Even a clear fore-and-aft view will sometimes show a displaced process.

Fractures of the transverse processes are more common in the lumbar spine and can be readily demonstrated in the usual view of this region. Because of muscular action and the inability to enforce absolute rest, these fractures frequently do not unite, at least not for a long period (Figs. 94

and 95). Instances have been reported of a separation in the first lumbar transverse processes with a line simulating an articulation (Fig. 96). Fractures in the thoracic transverse processes are less frequent and are easily overlooked, although they can usually be detected in clear roentgenograms.

Occasionally fractures occur in the ossifications that are found in

FIG. 93.—LATERAL VIEW OF THE CERVICAL REGION, SHOWING A FRACTURE OF THE SPINOUS PROCESS OF THE FOURTH VERTEBRA.

connection with advanced cases of hypertrophic spondylitis. These are important and should not be disregarded, as they are sometimes the underlying cause of severe pain following injuries of moderate severity. It is no doubt possible for small fragments of bone to become detached from the edges of the bodies of the vertebrae, but probably the small shadows frequently seen in the intervertebral spaces are more often not due to fractures (Fig. 97). These shadows are not uncommon in cases in which

FIG. 94.—OLD FRACTURES OF THE LEFT TRANSVERSE PROCESSES OF THE THIRD AND FOURTH LUMBAR VERTEBRAE.

The patient, an adult male, was injured several months previously, but the correct diagnosis was not made and the cause of his pain and disability not discovered until roentgen examination showed the exact condition. Note that the fragments are widely separated and ununited.

FIG. 95.—OLD FRACTURE OF RIGHT TRANSVERSE PROCESS OF THE FIRST LUMBAR VERTEBRA.

The patient, an adult female, had injured her back several weeks previously, but the exact cause of the prolonged pain and disability was not discovered until revealed by the roentgen examination. The fragment is apparently ununited.

there is no history of injury, and the only explanation of their presence is that they are possibly due to areas of calcification in the intervertebral disks. In some instances the shadow will be found to grow larger if the patient be examined from time to time.

Fractures of the posterior arches are, of course, especially important because of their close relations with the cord. Neither their presence nor

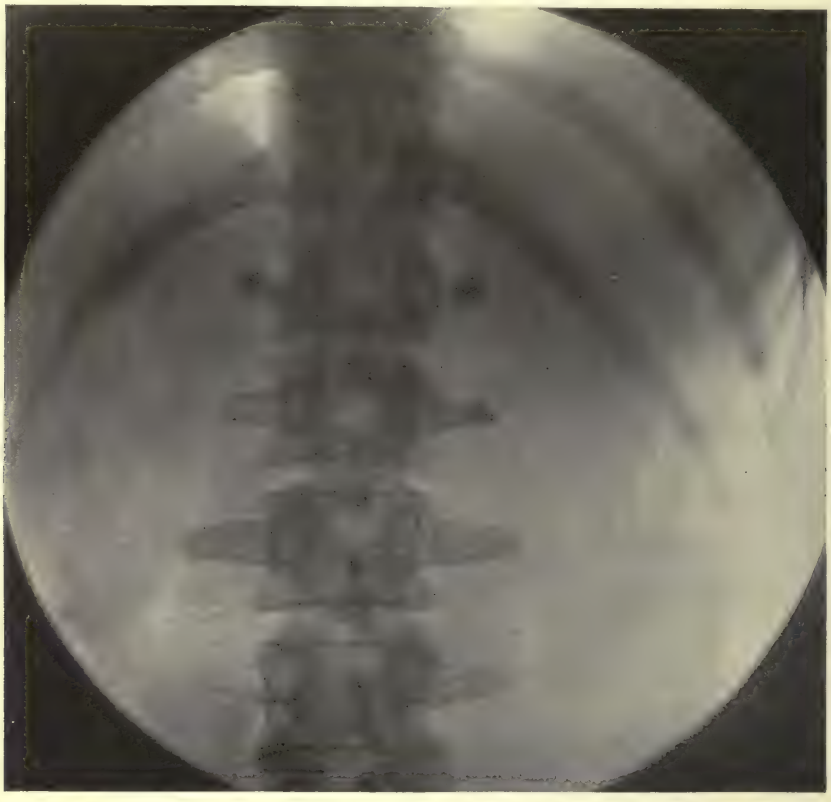

FIG. 96.—CLEFT IN TRANSVERSE PROCESS ON EACH SIDE OF THE FIRST LUMBAR VERTEBRA, WITH AN APPARENT ARTICULATION IN EACH PROCESS.

This is not due to delayed epiphyseal union, as this patient was a female aged 40 years. The condition may be present on one or both sides, and is of medicolegal importance as well as of scientific interest.

the extent of encroachment on the cord can be accurately determined unless satisfactory lateral views can be obtained, and in the thoracic region this is exceedingly difficult and usually impossible. In the neck it is a very simple procedure, and a satisfactory side view can be obtained in the lumbar region if the patient be not too stout and can be placed in an advantageous position. It is useless to attempt such views with a patient on a water bed. If the laminae of the lumbar vertebrae be involved in the region of the articular processes, the lesion may be shown in a clear

anteroposterior view, if there be ample intervertebral space and no decided deformity from luxation.

Usually in fractures of the body the anteroposterior view gives little more information than to demonstrate the seat of injury. It does not, as a rule, indicate the full extent, and in case of an accompanying dislocation or fracture of another portion of the vertebra, it gives no idea

FIG. 97.—SHADOW OF THE DENSITY OF BONE BETWEEN THE BODIES OF THE SECOND AND THIRD LUMBAR VERTEBRAE.

At first this was thought to be due to a detached fragment, especially as there was localized pain and tenderness in this region, but there was no history of injury. The same appearance has been observed in other individuals without any traumatic history, and in one instance the shadow was seen to increase in size on repeated examinations several months apart. The appearance may arise from localized calcification in the disks, and is of medicolegal importance.

as to the amount of encroachment on the canal and pressure upon the cord (Figs. 98 and 99). In the cervical region, body fractures can usually be satisfactorily determined only by the lateral view, which at the same time shows any accompanying injury to best advantage. Fractures of the thoracic bodies are more difficult to show and oblique or side views are required to demonstrate them to advantage, but unfortunately neither view shows an accompanying injury satisfactorily. In the lumbar region the determination of the exact extent and nature of a body fracture will de-

FIG. 98.—OLD FRACTURE-DISLOCATION INVOLVING THE THIRD AND FOURTH LUMBAR VERTEBRAE, AND UNUNITED FRACTURES OF THE RIGHT TRANSVERSE PROCESSES OF THE SECOND, THIRD AND FOURTH.

Patient, a male, aged 20 years, injured by a fall on board ship nine months before, who recovered and was able to walk. Referred for supposed tuberculous spondylitis, because of pain, spasticity and kyphosis, but no evidence of such a lesion found.

pend upon a side view, although the presence of the fracture can be readily demonstrated in the opposite direction. Fractures of the body or wings of the sacrum can be easily shown, provided clear roentgenograms are ob-

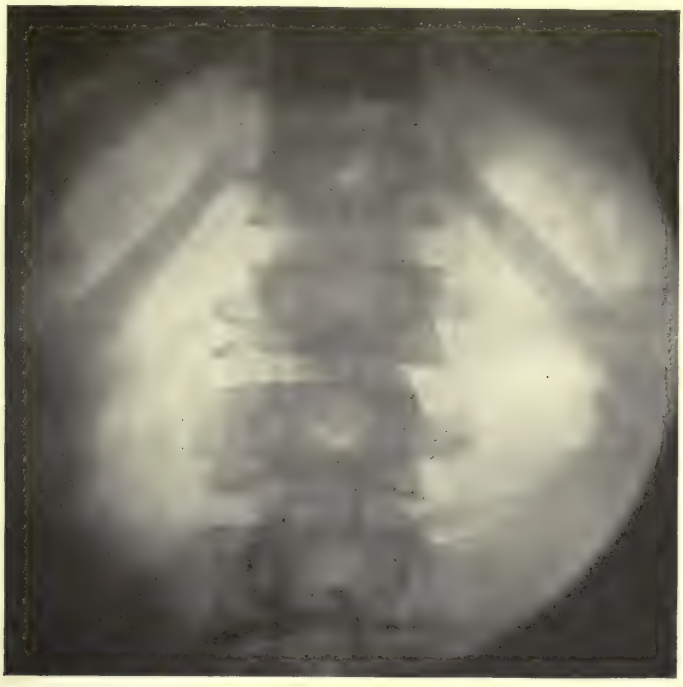

FIG. 99.—FRACTURE-DISLOCATION INVOLVING THE FIRST AND SECOND LUMBAR VERTEBRAE. The patient, a male aged 22 years, was hurt in a collision between a motorcycle and an automobile. The lateral displacement shows the seat of injury, but otherwise the anteroposterior roentgenogram gives no indication of the full extent of the lesion nor the amount of encroachment upon the cord. There was complete paralysis below the seat of injury.

tainable. In all instances, stereoscopic plates of spine injuries possess distinct advantages over single exposures in one or both directions.

FRACTURE-DISLOCATIONS

This term, as usually employed, implies a fracture together with an associated permanent disjunction with displacement shown by the roentgenogram or found at operation. It is well known, however, that a fracture may be accompanied by a transitory dislocation, which is immediately replaced, but which in reality may have been the factor concerned in the cord injury. Such injuries are common in the cervical region and the only evidence found at the examination may be a slight fissure through a body or a small detached fragment of bone, of no great significance in

itself, and merely indicating the seat of the injury. In the cervical region the severity of the trauma to the spine frequently bears little relation to the cord injury. In some of the most severe injuries to the cord there is often comparatively little roentgenographic evidence of traumatism to the spine, while, on the other hand, there may be a very serious fracture with permanent dislocation and marked displacement with little or no cord disturbance. Such injuries are usually rather high up, from the second to the fourth or fifth cervical vertebra, but extensive injuries lower down are invariably serious (Fig. 102).

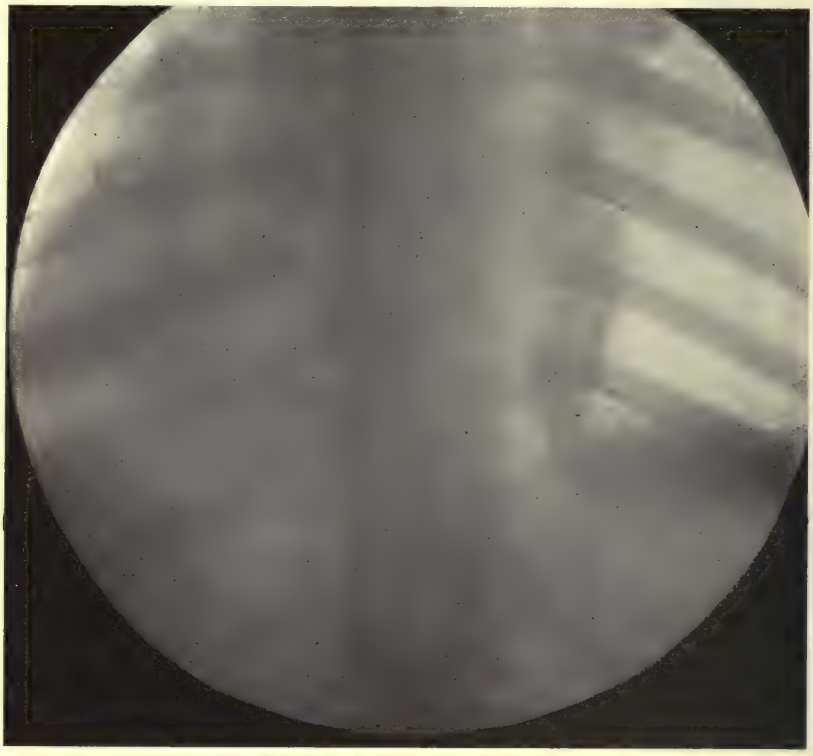

FIG. 100.—ANTEROPOSTERIOR VIEW OF FRACTURE OF THE TWELFTH THORACIC VERTEBRA AND ANTERIOR DISLOCATION OF THE ELEVENTH. (Doyle.)

Patient was a sailor who fell from the rigging of a vessel to the deck. Note that the extent of the injury is not shown in this view.

Fracture-dislocations in the thoracic region are exceedingly difficult to recognize. In the lumbar region their presence is readily detected in the anteroposterior view, but the lateral or stereoscopic views are necessary to determine their exact nature and extent.

Pure dislocations at the lumbosacral joints, often unilateral, are quite common, but may easily escape notice unless stereoroentgenograms be made. Spondylolisthesis may be suspected if the shadow of the lower

border on the fifth lumbar vertebra in the anteroposterior view seems to project below the line of the promontory of the sacrum. A lateral view, although difficult to obtain, and always lacking in clear details, may show

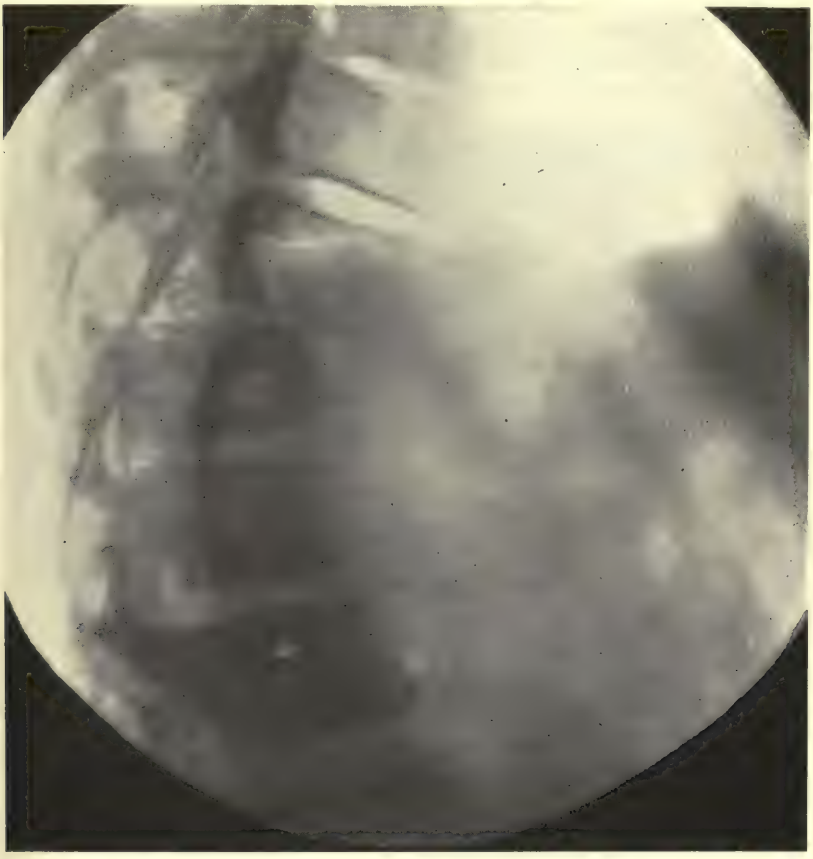

FIG. 101.—LATERAL VIEW OF THE SAME CASE AS FIG. 100, SHOWING THE DISLOCATION OF THE ELEVENTH THORACIC VERTEBRA. (Doyle.)

the fifth lumbar body projecting well beyond the anterior aspect of the body of the sacrum (3).

TUMORS

The roentgen diagnosis of tumors of the spine or cord is confined entirely to those growths which involve the bony structures and produce either new bone formation or a loss of osseous substance sufficient in extent to be demonstrable in the roentgenograms. Tumors of the cord cannot be diagnosed by this method, and if by any chance they involve the vertebrae secondarily the appearance is in no way suggestive of their pri-

mary origin. The new growths which are found in connection with the vertebrae are exostoses, sarcoma, metastatic carcinoma, and there might also be included the invasion sometimes found late in pseudoleukemia. Exostoses are uncommon except in the form of osteophytes found in connection with advanced cases of hypertrophic spondylitis.

In the late stages of pseudoleukemia, and especially in the ultimately hopeless cases, in which general glandular enlargements have been in-

FIG. 102.—COMPLETE ANTERIOR DISLOCATION OF THE SIXTH CERVICAL VERTEBRA, WITH FRACTURE AND WIDE SEPARATION OF ITS SPINOUS PROCESS.

The patient, a male aged 60, was thrown from a coal wagon he was driving as it was struck by a locomotive. Note the complete encroachment upon the spinal canal. There was complete paralysis below the lesion. The patient's condition was too critical to warrant operation, and he died four days later.

hibited over a comparatively long period of time by roentgen treatment, lymphoid deposits may occur in the spine and in the structures within the canal. Such lesions are to be suspected under such circumstances when intense and obstinate referred pains are present and cannot be explained by pressure from glandular enlargements. In these cases the roentgenogram may show some areas of rarefaction in the vertebrae.

Sarcoma and metastatic carcinoma of the spine may be readily diagnosed in cases in which the bodies of the vertebrae are attacked. When growths originate in other portions, especially in the thoracic region, the diagnosis is far more difficult. Knowledge of the clinical picture is al-

ways essential in order to differentiate between these two growths, and also between one or the other of them and syphilitic osteomyelitis, tuberculous caries and post-typhoidal spondylitis, all of which have certain points of resemblance in their roentgen appearances.

The spine is a very common seat of metastatic carcinoma, especially as a sequel to growths in the breast and prostate. It is likely to occur very early in breast carcinoma and even in those cases which present the least malignant types of growths. In any case in which there is or has been a mammary carcinoma and the patient complains of persistent pains, which may be referable to a lesion in the spine, a roentgen investigation of the vertebrae should be made.

Carcinomatous lesions are very often multiple and involve other bones at the same time. If the vertebral body be attacked, there will be found at first a small area of rarefaction which gradually becomes more extensive and in part of which finally the bone structure entirely disappears, although sometimes the entire body may become rarefied before there is any very decided area of complete loss of bone structure. The lesion may invade the body at or near the upper or lower surface particularly and the disk may become infiltrated—in which case the appearance may closely resemble a tuberculous or post-typhoidal process. Clinical data will, of course, be necessary for a correct interpretation. Carcinoma seems to be more distinctly a gradual infiltrative process, destroying bone slowly in its advance, but there is not the tendency for the bone to widen out as frequently happens in sarcoma, although a pathological fracture may occur. The process is sometimes sufficiently slow for the surrounding bone to show evidence of condensation. Many writers describe a distinct osteoplastic type of carcinoma in which condensation either predominates at some period during the process or appears to comprise the entire process —in which case the entire body of one or more vertebrae may appear much denser than normal. Carcinomatous growths may be discovered when comparatively small in extent, but because of their serious nature one should hesitate in making a final diagnosis unless the bone structure of the suspected vertebrae is clearly shown in the roentgenogram.

The amount of referred pain may bear no close relation to the extent of bone involvement, as shown by the roentgenogram. In some instances, there may be extreme pain and spasticity in the presence of apparently a very small lesion. On the other hand, there may be evidence of an extensive lesion of the body with comparatively little referred pain.

Sarcoma may closely resemble carcinoma, especially in the early stages, but if it be a question as to which one of the two growths is present, the absence of any evidence of an existing or persisting carcinoma elsewhere will confirm the diagnosis of sarcoma. Sarcomatous growths of the spine are almost invariably single and the lesion is usually limited to the vertebra in which it originates. The body may be almost completely destroyed and

the laminae and articular processes invaded without the adjacent vertebra or disk being involved (Figs. 103 and 104).

The appearance in the body is usually characterized by a gradually increasing area of rarefaction, followed by complete disappearance of

FIG. 103.—SARCOMA OF THE THIRD LUMBAR VERTEBRA.

The case is of particular interest, first, because the growth was detected roentgenologically several months before there were any symptoms pointing directly to a spinal lesion, and, secondly, because the roentgen diagnosis of a neoplasm was not accepted by several clinicians and surgeons for some time. The patient, a male aged 65, was referred for a roentgen examination of the left hip and sacro-iliac region because of pain around the hip and in the thigh. Nothing was found in these localities, but, as a matter of routine, the entire lumbar spine was examined. There was found an area of rarefaction in the left side of the body of the third lumbar vertebra, with some new bone formation on the right side. Sarcoma, carcinoma and syphilis were the only conditions likely to produce such an appearance. Syphilis was excluded. There was reason to suspect metastatic carcinoma, but the presence of a primary focus was finally excluded. The roentgen diagnosis of sarcoma was confirmed at autopsy. This roentgenogram was made four months after the first examination. Note that the lesion is single and limited to one vertebra, nearly one-half the body being destroyed, but the articular processes remain intact. Pathological fracture had not occurred, since every effort had been made to prevent it. The process was comparatively slow and was no doubt delayed by vigorous though futile roentgen treatment, and there has been condensation of the remaining portion of the body and new bone formation on the opposite side. No doubt the presence of the growth has tended to prevent collapse of the body such as would appear in a suppurating or caseating process.

bone structure in the central part of the area, while the rarefaction spreads. The process is usually more rapid than carcinoma. Later the body may become widened out, presenting an appearance of having been disrupted, or a pathological fracture may occur. If the process be not very rapid there may be evidences of condensation in other portions of the vertebra. In such instances the appearance may closely resemble a syphilitic osteomyelitis, and may be distinguished from the latter only after a

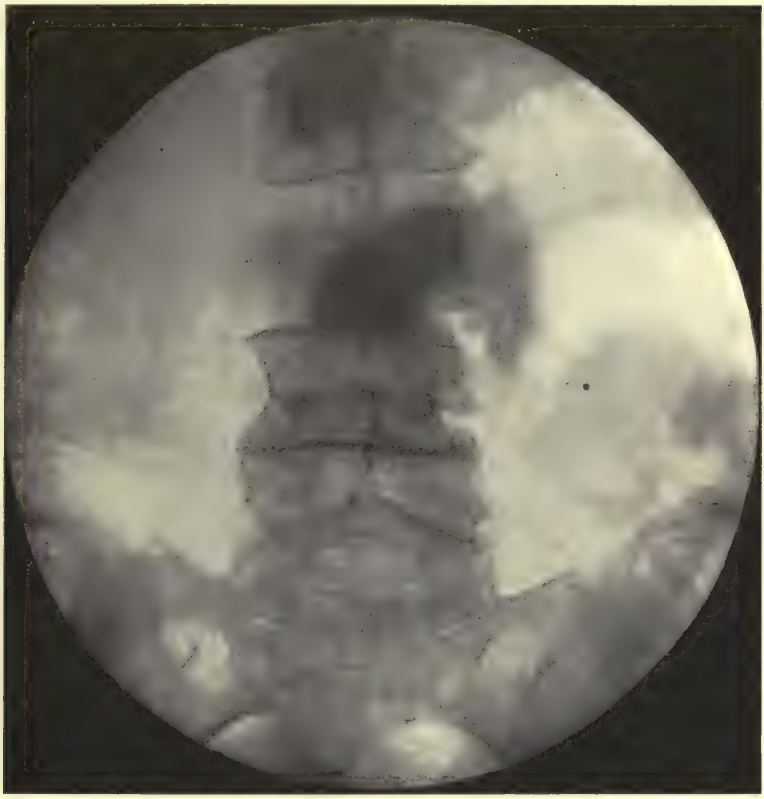

FIG. 104.—THE SAME CASE AS IN FIG. 103, THREE WEEKS LATER.

Note that the process has extended somewhat, has invaded the articular process, and the body is beginning to collapse.

negative Wassermann reaction has been obtained. If there be any question about the Wassermann reaction, the patient should certainly be given the benefit of the doubt and antisyphilitic treatment instituted; otherwise the condition is hopeless.

At certain stages, when bone destruction has advanced to such an extent that collapse of the vertebra would seem inevitable, were the process one of suppuration or necrosis, the diagnosis of neoplasm from tuberculosis or syphilis would be based upon the fact that the bone has remained

intact through the support given by the growth itself. In suppurative or caseating processes, deformity usually keeps pace with bone destruction. In neoplastic lesions, however, deformity is likely to occur as soon as the laminae and articular processes become decidedly involved. Roentgenographic evidence of a sarcomatous growth in a vertebral body may precede the pain due to pressure on the spinal roots, and localized tenderness may be absent for some time after the presence of the lesion can be demonstrated.

Malignant disease of the spine is the only condition in connection

FIG. 105.—BULLET LODGED IN PROXIMITY TO RIGHT SIDE OF SECOND CERVICAL VERTEBRA. Anteroposterior view, made through mouth.

with which roentgen treatment need be mentioned. Such cases are practically inoperable except for the relief of pain. Roentgen treatment is rarely likely to be of any permanent benefit, but it also may be employed at times in the attempt to relieve pain. In carcinoma it becomes a matter of treating one of many metastases—a rather hopeless task—without any idea of a permanent result in view. In sarcoma the growth is often primary and localized, and at least some inhibitive effect may be induced, in addition to the possible relief from pain, by means of modern crossfire roentgen radiation directed through every possible port of entry around the body.

FOREIGN BODIES

The usual foreign bodies lodged in relation with the spine and in the spinal canal are bullets and the various missiles of warfare. Exact roentgen localization is essential to determine whether their presence is likely to do harm, the amount of damage they have inflicted, whether they are accessible for removal, their exact location and the best means of approach. The various devices and methods for exact localization from sur-

FIG. 106.—SAME CASE AS IN FIG. 105, LATERAL VIEW.
These two views show the bullet in close contact with the spine.

face points are of comparatively little value, unless in addition the foreign body is shown in its intimate relations with the various portions of the vertebrae. This may be accomplished by making two views at ninety degrees (Figs. 105 and 106), or, better, by the stereoscopic method.

CONGENITAL ANOMALIES AND DEFICIENCIES

Considering the fact that the spine, the cord and its membranes are first formed by the union of symmetrical halves, and that subsequently the formation of the various portions of the vertebrae depends upon the

appearance and development of numerous centers of ossification, the spine can be regarded as a potential seat for very frequent defects in development.

Congenital deficiencies and anomalies may be divided into two groups: (1) those dependent upon failure of union of the two symmetrical halves of the embryonal structure; and (2) those arising from the failure of centers of ossification to form or develop normally.

(1) **The first group** comprises those deficiencies usually classed under the clinical term *spina bifida,* and due to failure of complete closure of the

Fig. 107.—Spina Bifida in Male Child, Aged 9 Months; Lateral View.

medullary tube after the formation of the medullary groove in the embryo. There are four types belonging to this group:

(*a*) Rachischisis.—In this type the entire spinal portion of the medullary groove remains open, and at birth the spine and spinal canal are represented by a shallow groove in which are exposed varying amounts of rudimentary nerve structure and membranes of the cord lying upon the vertebral bodies. This deficiency may involve all or a part of the spine. A roentgen examination of what virtually is a monster is of scientific interest only (2).

(*b*) Spina Bifida.—This is the term employed to designate failure of union of the symmetrical halves of the medullary tube. The several

varieties, meningocele, meningomyelocele and syringomyelocele or myelocystocele, depend upon the contents of the tumor. The roentgen examination is of little or no value in distinguishing between these varieties, and practically its only use is the determination of the location and extent of the defect in the vertebral arch. In infants and very young children the examination even for this purpose is usually unsatisfactory because of the presence and location of the large tumor mass, which offers decided ob-

FIG. 108.—CONGENITAL ABSENCE OF THE LOWER HALF OF THE SACRUM, DEFICIENCY IN DEVELOPMENT OF THE RIGHT SIDE OF THE FIFTH LUMBAR VERTEBRA, CAUSING A SCOLIOSIS, AND FAILURE OF UNION OF THE POSTERIOR ARCH OF THIS VERTEBRA. Female, aged 15 years.

stacles to a satisfactory anteroposterior view (Fig. 107), and because of the comparatively small amount of ossification present at so early an age.

(*c*) SPINA BIFIDA ANTERIOR.—While most cases of spina bifida are due to failure of union posteriorly, in rare instances the defect may be anterior, involving the body of the vertebra. A sac may then project forward into the abdominal cavity. Such a defect is more readily shown in the roentgenogram than the more common type.

(*d*) SPINA BIFIDA OCCULTA.—This type of deficiency includes various defects due to failure of closure of the vertebral arches without any associated protrusion or tumor. In such cases an area of hypertrichosis

is frequently found over the defect. Roentgen examinations show such defects to be far more common than was formerly realized. They may also involve the bodies of the vertebrae. Absence of the lower portion of the sacrum, a rather frequent anomaly (Figs. 108, 109), might, in some instances at least, be included in this group. The most common example

FIG. 109.—CONGENITAL LACK OF DEVELOPMENT OF THE LUMBAR SPINE AND SACRUM, WITH SPINA BIFIDA OCCULTA.

The lower portion of the sacrum is missing. It is difficult to determine the exact deficiencies in the lumbar vertebrae, but at least the body of the fifth is missing.

of posterior spina bifida occulta is the failure of union of the posterior arch of the fifth lumbar vertebra (Fig. 110). This is found by the roentgenogram in a fairly large percentage of apparently normal individuals, and in some instances has been mistaken for a fracture when found in patients examined for an injury to this region. The same condition is not uncommon higher up, and especially in the thoracicolumbar region (Fig. 111). The spinous processes appear to be lacking in these cases.

(2) **The second group** of congenital anomalies, comprising those due

to failure of centers of ossification to form or develop normally, has been found with greater frequency since the advent of roentgen diagnosis. In order to understand these anomalies and to classify them correctly a knowledge of the development of the osseous structure of the vertebrae

FIG. 110.—FAILURE OF UNION OF THE POSTERIOR ARCH OF THE FIFTH LUMBAR VERTEBRA, DISCOVERED AT ROENTGEN EXAMINATION OF AN ADULT MALE FOR URINARY CALCULUS.

This defect is found in a large percentage of normal individuals, but has been mistaken for a fracture in some instances.

is essential. Each vertebra ossifies from three chief centers (5): a median one for the body, and one on each side for the pedicle, adjacent portion of the body, arch, and the greater part of the processes. These centers are partially ossified at birth. As the lateral centers do not entirely fill the posterior gap in the arches for several months after birth, the failure to show a complete bony arch in the roentgenogram must not be mistaken

for a spina bifida occulta. Secondary centers appear later for the tips of the spinous and transverse processes, upper and lower surfaces of the bodies, mammillary processes in the lumbar region and the costal elements of the sixth and seventh cervical and the first lumbar vertebrae. A similar process of development is found in the sacrum, with a median primary center for the body of each sacral vertebra and one for each of the lateral masses, but these do not join so early as those in the upper vertebral segments. Secondary centers appear later for the margins of the sacrum and the articular surfaces.

FIG. 111.—FAILURE OF UNION OF THE POSTERIOR ARCHES OF THE ELEVENTH AND TWELFTH THORACIC AND FIRST LUMBAR VERTEBRAE IN A BOY AGED 14 YEARS.

The spinous processes of these vertebrae are absent. This is a common defect in this region, but cannot be discovered by physical examination.

In any portion of the body where ossification centers are numerous, as in the carpus and tarsus, deviations from normal development are frequent, and this is the case also in the spine, where they may produce no apparent defect until one is discovered by the roentgen examination, or may be responsible for serious defects or marked asymmetry. One of the most common anomalies is a variation in number, which may be either a variation in one region fully compensated for in the adjacent portion, or there may be one vertebra too many or too few in one region without compensation elsewhere. The most common seat of such variations is in the lumbar region, where there may be either four or six vertebrae (Fig. 112), but in order to determine whether this is compensated for elsewhere, the entire spine should be examined. For example, a pair of

lumbar ribs may give one the idea that only four lumbar vertebrae are present.

Another series of very common anomalies arises from failure of de-

FIG. 112.—COMPLICATED ANOMALY OF THE SPINE OF A FEMALE, AGED 13 YEARS.

The exact condition could not be interpreted without an examination of the entire spine, as there are twelve ribs on the right side and only eleven on the left, and the right twelfth rib may be mistaken for a lumbar rib springing from the first lumbar vertebra. There has evidently been a defective development of the left lateral mass of the first lumbar, causing a scoliosis. In addition, there has been either a fusion of the second and third vertebrae or an excessive development of the right lateral mass of the second, with the formation of only four lumbar vertebrae. The first sacral resembles a sacralized lumbar vertebra.

velopment of one or more of the centers or variations in ossification. Most of these may be detected by the roentgen examination. In rare instances the median center for the body may be absent. It would be practically

impossible, in many instances at least, to determine by the roentgen examination whether such a defect is a true spina bifida anterior or is due to failure of ossification of the center or to absence of the center. In the latter instance the bony defect would be represented by other tissue, as has been reported in the case of the atlas (5).

FIG. 113.—COMPLICATED ANOMALY OF THE SPINE AND RIBS IN A MALE, AGED 8 YEARS.

There are double rudimentary cervical ribs, eleven thoracic vertebrae, twelve thoracic ribs on the right side and eleven on the left. There is an excessive development of the right lateral mass of the seventh cervical and a defective development of the corresponding portion of the first thoracic. The fifth thoracic vertebra is represented only by the lateral mass on the right side, from which a fifth rib arises. A corresponding rib is missing on the left side. The latter anomaly of the spine is responsible for a congenital scoliosis. (Patient referred by Dr. G. G. Davis.)

Far more frequent are anomalies resulting from complete absence or only partial ossification and development of the lateral masses. Such a defect is found not infrequently in the upper thoracic region with a resulting congenital scoliosis (Fig. 113) and is often associated with anomalous conditions in the ribs. The most frequent seat of these anomalies, however, is in the lumbosacral region where a wide diversity of

atypical deviations may arise from numerous variations in development of the lateral masses. The fifth lumbar vertebra is in some respects transitional between those above and the sacral vertebrae. Its transverse processes arise not only from the pedicle, as in those above, but also from the

FIG. 114.—A PARTIALLY SACRALIZED FIFTH LUMBAR VERTEBRA IN A FEMALE AGED 18 YEARS.

The costal elements on each side have undergone excessive development, but there has been no attempt to articulate with the ilia.

sides of the body, and represent both transverse processes and ribs, just as do the lateral masses of the sacrum. Owing to variations in these combined costal elements in either the fifth lumbar or the first sacral vertebra, there results a large number of anomalies. The costal element of the fifth lumbar vertebra may be excessively developed on one or both sides (Fig.

114), and become sacralized or, in other words, articulate more or less extensively with the ilium (Fig. 115); or, on the other hand, the first sacral vertebra may be more or less independent of the second and resemble a sacralized sixth lumbar (Fig. 116). This is a description in a few words of the lumbosacral anomalies to which much attention is now being paid by orthopedic surgeons.

FIG. 115.—A CASE OF TRUE SACRALIZATION OF THE FIFTH LUMBAR VERTEBRA IN A FEMALE AGED 37 YEARS.

The costal element on the left side has become excessively developed and articulates with the ilium and sacrum. The patient was examined for localized pain and psoas spasm on this side. It is always necessary to examine the entire lumbar spine in order to determine which type of the anomaly exists.

The roentgen examination is, of course, the only means of accurately determining these anomalies, which become important solely when they are productive of symptoms. For example, the natural range of motion between the fifth lumbar and first sacral vertebrae may be restricted by such an anomalous development of the lateral masses; these become, as it were, the fulcrum of a lever and are subject to unusual stress, and their

articulations may be the seat of strains or arthritis (6). One other developmental variation in this region might be mentioned in this connection. The outward curve of the posterior portion of the iliac crests may

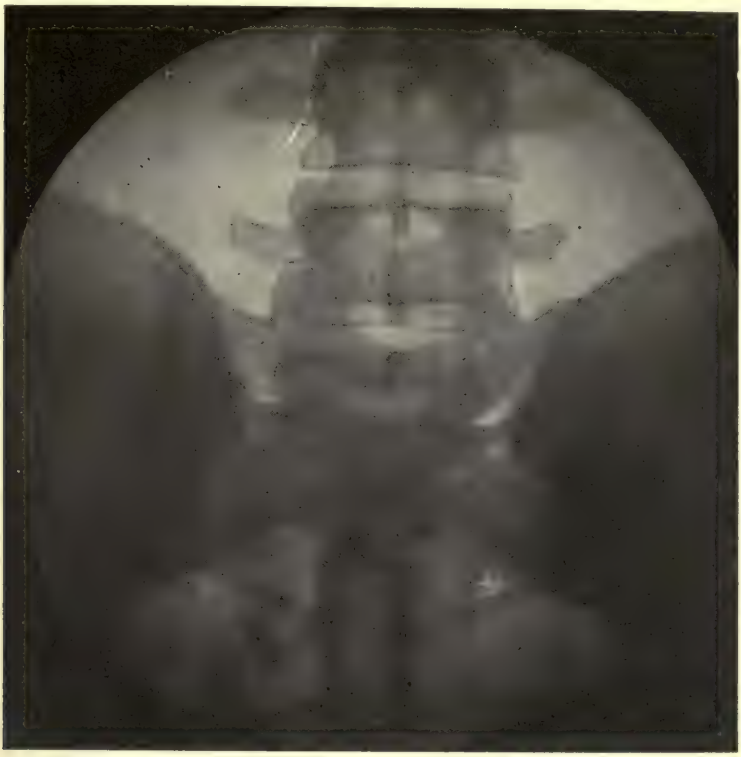

FIG. 116.—EXAMPLE OF THE SECOND TYPE OF LUMBOSACRAL ANOMALY IN A MALE, AGED 24 YEARS.

There were no symptoms. The first sacral vertebra has developed more or less independently of the second, and resembles a sacralized sixth lumbar vertebra.

begin high up and abruptly and be in such close relation with the transverse processes of the fifth lumbar vertebra that the ends of the latter may on certain motions impinge upon the ilia.

INFLAMMATIONS

The inflammatory processes involving the spine, in which the roentgen examination is of value in diagnosis, are chronic hypertrophic spondylitis, tuberculosis, typhoid spondylitis, syphilitic osteomyelitis and acute and chronic osteomyelitis of pyogenic origin.

Chronic Hypertrophic Spondylitis.—Very early bone and joint

changes may be noted in this condition, but it should be borne in mind that these same changes or similar ones, when found as they are in spines of individuals of advancing years, are not strictly pathological and give rise to

FIG. 117.—CASE OF ADVANCED HYPERTROPHIC SPONDYLITIS IN A MALE, AGED 25 YEARS.

The intervertebral spaces in the lumbar region have become entirely bridged over by osseous deposits in the ligaments. The appearance suggests that fractures have occurred in these ossified ligaments between the third and fourth and fourth and fifth vertebrae on the left side. (Patient referred by Dr. J. B. Carnett.)

no symptoms. Therefore, when slight changes are present it does not necessarily mean that the condition they represent is the cause of the patient's symptoms. In studying this condition from the roentgenologic standpoint, the spine must be regarded in the light of a complex series of

joints, and the appearances shown are to be regarded as similar to those found in connection with hypertrophic arthritis in joints most frequently the seat of this condition—namely the knee and hip. Two very early changes may be noted:

I. The appearance of the intervertebral joints may suggest atrophy of the articular cartilage by a closer approximation of the articular surfaces. Extreme caution must be exercised in interpreting such appearances, however, as the intervertebral joint spaces vary greatly in different individuals and in different joints in the same individual, and the effect of variations in the angles of these joints may be very misleading. In addition, very slight hypertrophic changes or thickening may be noted around the articular margins. Naturally such changes are best seen where the intervertebral joints show to best advantage—namely in the cervical and lumbar regions. One should not attempt to interpret such changes unless the roentgenograms are clear and bone architecture is clearly depicted.

FIG. 118.—EARLY TUBERCULOUS LESION IN THE CENTER OF THE BODY OF THE SECOND CERVICAL VERTEBRA IN A FEMALE AGED 6 YEARS.

This diagnosis was confirmed later by the destruction of a large portion of the body.

II. Small osteophytes may be seen projecting from the margins of one or more vertebrae, sometimes giving them a lipped appearance. This may be exaggerated in the aged, where there is a tendency to lipping, through an apparent flattening of the bodies and widening of the edges. As later changes in the true pathological cases, the lipping increases and the intervertebral spaces may become entirely bridged over (Fig. 117), and finally the disks become calcified and the vertebrae ankylosed. These late changes are readily demonstrable in the cervical and lumbar regions, and in the thoracic vertebrae in lateral or oblique views.

Tuberculous Spondylitis.—As tuberculous disease usually attacks the bodies and disks, the roentgen examination is valuable and always important, although the diagnosis in early stages is sometimes difficult, especially in infancy. One of the most characteristic roentgenologic features of tuberculous disease here, as elsewhere, is the entire absence of new bone formation and condensing osteitis, this being one of the indications ad-

vanced for bone transplantation to promote ankylosis. The lesion may start as a focus in the center of the body (Fig. 118), but the disease more often attacks the anterior portion, and as the process disintegrates the osseous structure the body begins to crumble. As the center of gravity

FIG. 119.—OLD TUBERCULOUS DISEASE IN THE LUMBAR REGION IN A FEMALE AGED 9 YEARS.

Note that in this anteroposterior view we are unable to localize the lesion. (*Vide* Fig. 120.)

FIG. 120.—LATERAL VIEW OF THE SAME CASE AS IN FIG. 119.

Showing that the disease has destroyed almost the entire body of the third lumbar vertebra, leaving only a wedge-shaped portion, and has also involved the lower anterior portion of the body of the second.

is in front of the centers of the bodies, or is more often thrown there, and the vertebrae are firmly united posteriorly by the joints and ligaments, the body begins to collapse anteriorly, and finally becomes wedge-shaped (Figs. 119 and 120), and may eventually disappear (Figs. 121 and 122). The extent of involvement may be best shown by the lateral view, although the diagnosis can usually be made and the lesion located by the anteroposterior roentgenogram. Occasionally, however, it can be detected only in the former (Figs. 123 and 124). The lateral view is important also in showing the amount of deformity and whether this is the probable cause of cord or root pressure. After bone transplantation for fixation the roentgenogram is of value in showing the condition and position of the

bone graft and in detecting a possible fracture therein. If it cannot be well shown in a lateral view, sometimes a rather weak underexposed anteroposterior plate will demonstrate it to best advantage.

Tuberculous abscesses usually contain a certain amount of bony detritus and cast a mottled, sausage or spindle-shaped, or rounded shadow around the seat of disease. The roentgenogram may, therefore, be of value in determining the position and extent of such a lesion.

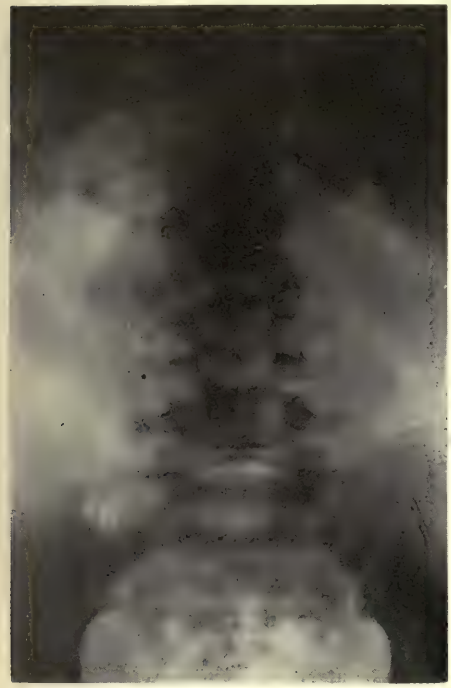

FIG. 121.—OLD TUBERCULOUS DISEASE IN THE LUMBAR SPINE IN A MALE AGED 7 YEARS.

Note that this anteroposterior view gives no idea of the exact seat or extent of the lesion. (*Vide* Fig. 122.)

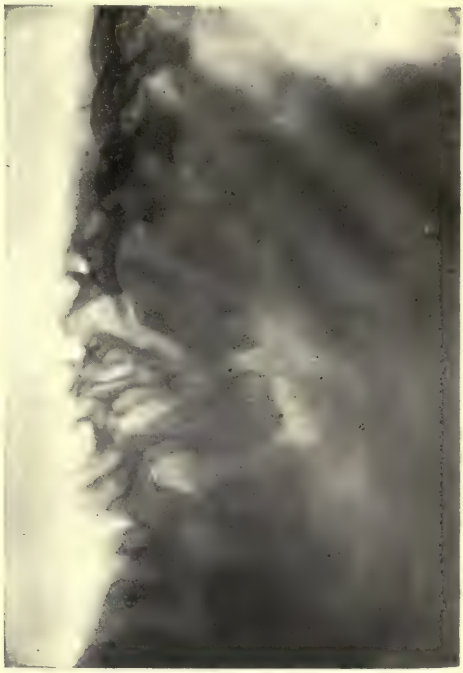

FIG. 122.—LATERAL VIEW OF THE SAME CASE AS FIG. 121.

Showing that the disease has completely destroyed the body of the second lumbar vertebra.

Deformities are not always the determining factors in cord or root pressure. The tuberculous process may extend posteriorly and invade the anterior portion of the spinal canal and cause a meningitis, or the exudate may enter the canal and cause irritation or pressure. In such instances the roentgen examination will not show the cause of the disturbances in function or sensation.

Syphilis of the Spine.—Syphilitic osteomyelitis of the vertebrae presents the same general roentgenologic characteristics as bone syphilis else-

where. These are bone destruction with associated condensing osteitis and new bone formation (Fig. 125). The destructive process may be slow and appear as a rarefying osteitis, or it may be greatly in excess, with gumma

FIG. 123.—TUBERCULOUS DISEASE IN THE LOWER THORACIC REGION IN A FEMALE AGED 7 YEARS.

In this anteroposterior view the lesion would seem to be between the first and second lumbar vertebrae. (*Vide* Fig. 124.)

formation or necrosis, in which case there may occur a collapse of the vertebra or a pathological fracture. From the roentgenologic standpoint, it is most likely to be mistaken for tuberculosis, carcinoma or sarcoma. The diagnosis must depend upon a positive Wassermann reaction, with or without a history of syphilis. In tuberculosis new bone formation and

condensation do not accompany the destructive process. In carcinoma there must be a history of a primary growth elsewhere, and in either of the malignant growths excessive new bone formation is not likely to occur. Charcot's spine should be mentioned in connection with syphilis, as the processes in each are similar. In the former, destruction is usually more

FIG. 124.—LATERAL VIEW OF THE SAME CASE AS IN FIG. 123.
Showing that the disease has involved the anterior portions of the upper and lower surfaces of the eleventh and twelfth thoracic vertebrae and the intervening disks.

rapid, there are irregular small shadows around the partially disintegrated vertebra, representing bony detritus, and there is apt to be considerable irregular new bone formation such as condensation and osteophytes.

Typhoid Spondylitis.—Certain very definite and characteristic changes are to be observed in this condition, but unfortunately they are not shown until the process has been active for a considerable period of time, when a destructive process becomes manifest. In most cases this is not observed for several weeks after the onset of symptoms or even not until

they have begun to ameliorate to a certain extent. Therefore, simply because the roentgen examination is negative in a case of suspected post-typhoidal spondylitis, this is no indication that such a process is not present and active.

FIG. 125.—SYPHILITIC OSTEOMYELITIS OF THE THIRD LUMBAR VERTEBRA IN A MALE AGED 34 YEARS.

The destructive process has involved the central portion of the body which has collapsed and spread apart. The lateral portions show a marked condensing osteitis and thickening. The only manifestations of note were a slight kyphosis and some weakness in the lower extremities, so that the patient was obliged to use a cane. Wassermann reaction positive.

The lower thoracic and lumbar regions are those usually affected and the lesion is, therefore, comparatively easy to demonstrate. The first change to be noted may be a diminution in the width of an intervertebral space in the suspected region, due to an enchondrosis and resulting suppuration or absorption of cartilage. Unlike other typhoid bone lesions, however, suppuration is infrequent, though it can occur, and may develop (1), with comparative rapidity, that is, within a few days or in two or three weeks. The accompanying osteitis may be indicated by some slight roughness or irregularity of the adjacent surface of the affected vertebra. These changes are always best shown in the lateral view. The intervertebral space rapidly becomes narrower, and finally the two adjacent bodies come together (Figs. 126, 127). Accompanying these changes, but manifest later in the roentgenogram, are periosteal thickening and calcification

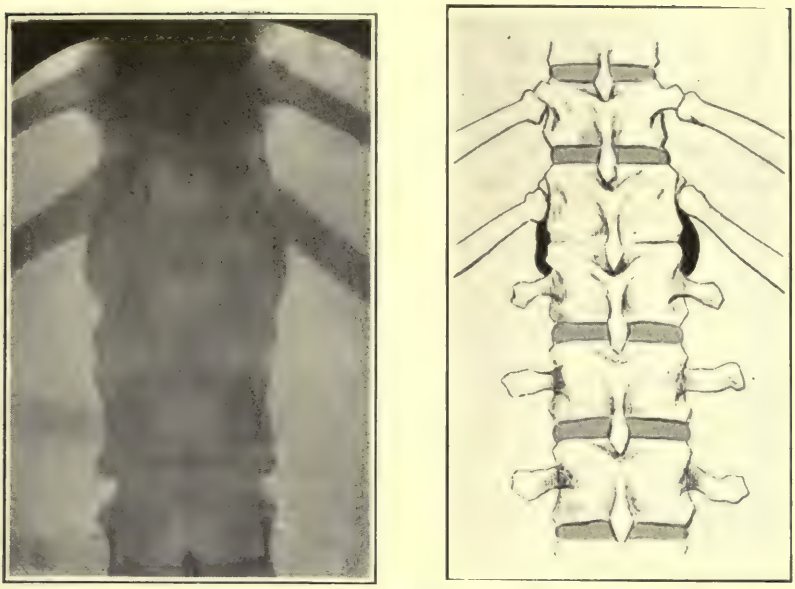

FIG. 126.—ROENTGENOGRAM AND DIAGRAM OF THE ANTEROPOSTERIOR VIEW OF CASE OF TYPHOID SPINE, TAKEN SEVEN YEARS AFTER ONSET OF SYMPTOMS. (Carnett.)

of ligaments in the immediate neighborhood, and the two bodies finally become ankylosed, and may appear as one, at least in the anteroposterior view, although the lateral view may continue to show evidence of some

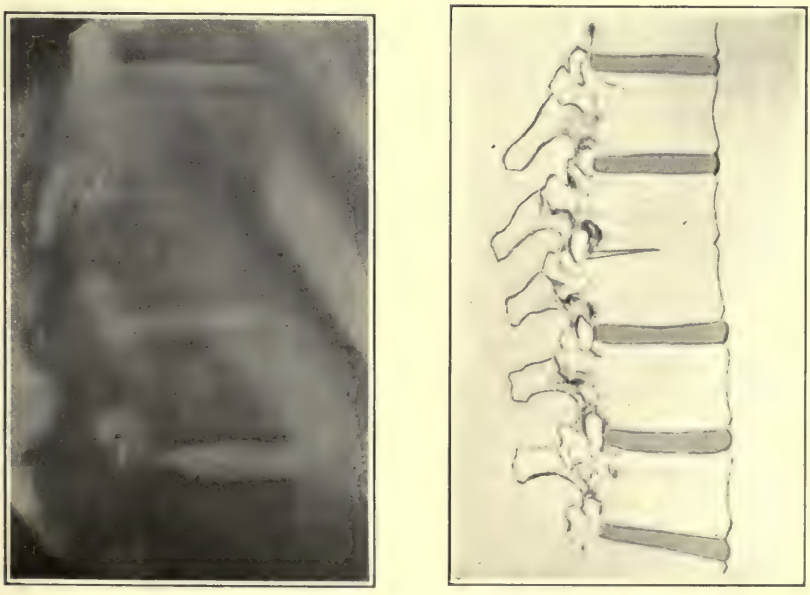

FIG. 127.—ROENTGENOGRAM AND DIAGRAM OF SAME CASE OF TYPHOID SPINE AS FIG. 126; LATERAL VIEW. (Carnett.)

cartilage remaining, especially posteriorly. The appearance differs mai terially from tuberculous disease in that the body is not so much affected in the destructive process as the disk, unless suppuration occurs, and the destruction seems to be fairly uniform throughout, and not so much limited to the anterior portion. Moreover, new bone formation is not a part of tuberculous bone lesion.

Acute Osteomyelitis.—This condition seems to be extremely rare in the spine and has been observed by very few roentgenologists. It may affect the body or arches. Just as in acute osteomyelitis or epiphysitis elsewhere, the roentgenogram will show no evidence of the lesion in the early acute and most dangerous stage. After the disease has been active for two weeks or more and suppuration has occurred, the bone structure may appear somewhat irregular, due to the destructive process, and a sequestrum may be shown then or later by very clear stereoscopic plates. Later on, of course, if the patient has survived, there will appear thickening and condensation. In the only case with which we are familiar, the disease involved the pedicle on one side of a lumbar vertebra, and a small sequestrum was discovered by stereoroentgenograms about two weeks after the onset of acute symptoms. After this localization, the sequestrum was removed and the patient recovered (4).

Chronic Osteomyelitis of Pyogenic Origin.—This is a far more common condition than the acute form, and, in the cases recognized, it is found as a diffuse variety. As the disease is more or less chronic from the start, sequestration is not so likely to occur as in the acute form. The roentgenographic appearance does not differ materially from that of tuberculosis or syphilis. Both disk and body may be involved. A condensing osteitis around the affected area, especially as resolution is taking place, together with late involucrum formation, are the main distinguishing features as regards tuberculosis. The disease is not so apt to affect the anterior portions of the bodies with the formation of wedge shaped remnants as in tuberculosis. Shadows of accompanying abscesses in the soft tissues may frequently be located as guides for operative procedures.

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CHAPTER V

SPINA BIFIDA

Spina bifida has been for many years a source of much perplexity to pediatrist, neurologist and surgeon, and, in spite of the fact that many excellent anatomical and pathological studies of this congenital anomaly have been made and various methods of treatment devised, we seem to be but little nearer the final solution of the problem. Have we been treading upon empirical ground in our treatment of spina bifida as we have been for so long in our treatment of hydrocephalus? Arrested development may truly be the prime etiological factor in spina bifida, but may there not be others of at least secondary importance? The fact that hydrocephalus is so often associated with spina bifida from birth or as a postoperative complication, suggests the possibility that increased cerebrospinal pressure may have a direct bearing upon this abnormality, either as a causative factor or as a closely allied condition. Such a case has recently come under my observation.

Spina bifida in a child nine months old. Through the defect in the upper lumbar region, there was a hernial protrusion extending from the eleventh thoracic vertebra down to and including all the lumbar vertebrae.

The patient, a little boy, *aet.* 9 months, was admitted to my service at the University Hospital, Sept. 22, 1915 (File No. 29855). He was the only child of parents who had been married three years; delivery was instrumental, and the baby was born asphyxiated. He could not move either of the lower extremities during the first two weeks, but by the third week he began to move the right leg slightly, and by the sixth the left. The head appeared larger than normal from the first, and at six months it measured 50 cm. There was, however, no increase in size between that time and his admission to the hospital and the meningocele also remained stationary. The hernial protrusion extended from approximately the eleventh thoracic vertebra down to and including all the lumbar vertebrae (Fig. 128). The overlying skin varied in thickness on the upper aspect and was bluish and translucent in places with an area of ulceration about the size of a fifty-cent piece. There was partial paraplegia of the lower extremities, and both feet were in a position of marked equinovarus. Partial ankylosis of the right knee joint was also present, and the left leg was a little longer than the right. The head was about normal in contour, but the forehead was prominent, and the fontanels unclosed. Neither exophthalmos nor strabismus was present. The roentgenogram showed a defect in the upper lumbar region and a clouding of the sac. The phthalein test indicated that the hydrocephalus was of the obstructive type, with possibly some delay in absorption.

If it be true that there is a close relation between spina bifida and hydrocephalus, we could scarcely look for permanent recovery after an operation which aims merely to remove the deformity and repair the defect, any more than that the solution of the problem in cases of hydrocephalus is ventricular or lumbar puncture. However this may be, the fact remains that spina bifida is one of the gravest of all congenital defects. It occurs approximately once in every thousand births, and of the infants thus afflicted, from eighty to ninety per cent die during the first year, many even within a few days of birth, and of the small percentage remaining, the majority are mentally defective and physically crippled. Through surgery there has been a small but perceptible reduction of the mortality of this ab-

FIG. 128.—A LARGE THORACICOLUMBAR MENINGOCELE WITH ASSOCIATED HYDROCEPHALUS.

normality which had rarely proved amenable to other forms of treatment. To be sure, there are many cases in which surgery is of no avail. Leaving out of consideration those stillborn or dying within a few hours of birth, there are many others unapproachable from the surgical viewpoint. On the other hand, a sufficiently large number of operative recoveries have been recorded to justify surgical intervention in carefully selected cases. It behooves us, therefore, to consider the problem from every viewpoint, that we may draw definite conclusions with regard to the indications and contraindications for intervention, the most auspicious moment to intervene, and the most effective methods of procedure, points concerning which there is at present absolutely no unanimity of opinion.

Of the various congenital abnormalities and defects involving the vertebral column or spinal cord, spina bifida is the only one of real clinical or surgical importance. Amyelia, atelomyelia, and diplomyelia are all extremely grave defects, either incompatible with life in themselves, or connected with other conditions which are immediately fatal. On the other

hand, slight abnormalities, such as asymmetry and heterotopy, give rise to no functional disturbances whatsoever, and have no special diagnostic signs. Hence, it is only the various anomalies, designated as spina bifida, which are of interest to the surgeon.

The term *spina bifida* was introduced by Nicolai Tulpius about the middle of the seventeenth century, and since that time has been generally adopted in the scientific world, despite several attempts to supplant it by other terms, such as hydrorachis, rachischisis, and the like. Etymologically, rachischisis from the Greek and spina bifida from the Latin are synonymous, both describing a cleft in the vertebral column, but since von Recklinghausen's classical monograph on spina bifida in 1866, rachischisis

FIG. 129.—CASE OF MENINGOCELE, WITH COMPLETE PARAPLEGIA AND MODERATE HYDROCEPHALUS.

has been used to denote a complete non-union of the walls of the medullary canal. This may extend the entire length of the cord (complete rachischisis) or it may be limited to certain segments (partial rachischisis), but the opening is always extensive and accompanied by other very grave defects, such as anencephalia, acrania or similar conditions; it, therefore, does not concern the surgeon.

On the other hand, under *spina bifida* are included those congenital defects in the vertebral column through which protrude some or all of the contents of the vertebral canal in the form of a cystic tumor, varying in dimensions from the size of a hazel nut to a child's head, and containing cerebrospinal fluid. While the skeletal defect is ordinarily in the arches of the vertebrae, the tumor protruding posteriorly (*posterior spina bifida*), in very rare instances the vertebral bodies are defective, with the hernia protruding anteriorly into the abdomen, pelvis, or thorax (*anterior spina bifida*). The walls of the sac may be composed of one or all of the membranes (*meningocele*), or of the membranes together with the

cord and roots, the cerebrospinal fluid being in the subdural or subarachnoid space (*meningomyelocele*), or the membranes and cord may protrude through the defect, and the collection of fluid may be in the more or less dilated central canal (*syringomyelocele*). In spina bifida, therefore, the essential feature is often not merely the defective development of the vertebral column, but an anomaly in the development of the cord and its protective coverings. As Mouchet has so clearly expressed it, "spina bifida should be regarded as a congenital malformation characterized by an evolutionary alteration in the perimedullary membranes and in many instances in the spinal cord itself, concomitant to the arrested development of one or more of the vertebral arches, and through the fissure thus created, a hernial tumor passes in a more or less constant manner." The abnormal accumulation of cerebrospinal fluid, moreover, is a fact which must ever be borne in mind. Its significance may be much greater than has been heretofore supposed.

Cruveilhier was one of the first to suggest arrested development as the cause for the malformation, a view corroborated by most authorities of recent years. Virchow (1863), Dureste (1877), Koch (1881) and von Recklinghausen (1886) have made important contributions to our knowledge of this subject, as did the Report of the Committee on Spina Bifida, appointed by the London Clinical Society in 1885, which upheld Cruveilhier's theory. It was von Recklinghausen who first described the various pathological types with their clinical characteristics, and on the basis of his research many attempts have been made to formulate definite ideas as to the propriety of operative intervention. More recently we have the works of Muscatello, of Bayer, of Moore, of Perlis and of Mouchet. Acknowledgment must be made to these and others for our knowledge and better understanding of the various forms of spina bifida and its complications.

Age and Sex.—Since spina bifida is a congenital defect, it is present from the moment of birth, although occasionally, especially in cases of spina bifida occulta, it does not manifest itself until a later date. It is a little more frequently found in females than in males, although the 68 cases which occurred at the New York Lying-in Hospital were equally divided as to sex. Of the 57 cases personally observed by Demme, there were 31 in females and 26 in males, and Moore further corroborates this statement by his findings in 385 cases, of which 102 were in females and 98 in males, the sex not being mentioned in the remaining cases. Out of 44 cases of spina bifida treated in Hildebrand's clinic, 24 occurred in females, 16 in males and in 4 cases the sex was not given. Assembling these statistics, we find that there were in 486 cases 157 females, 140 males and 189 cases in which the sex was not given.

Incidence.—Statistics on the frequency of spina bifida are exceedingly scarce. However, after a careful review of the literature and the

available mortality statistics, we conclude that this malformation occurs approximately once in every thousand births. In a series of 91,600 confinements at the New York Lying-in Hospital there were 59 cases of spina bifida, an incidence of one in 1,552. Nine additional cases were sent into the Hospital for operation. Chaussier discovered 22 cases of spina bifida among 22,293 children at the Paris Maternité, while Demme reports 57 cases among 36,148 children, and the Report of the London Committee on Spina Bifida states that in the year 1882 there were 647 deaths from spina bifida in England and Wales alone.[1]

Embryology of the Spinal Cord.—To understand the mode of development of the different types of spina bifida brief reference is made to the development of the spinal cord and vertebral column in the normal embryo. The anlage of the spinal cord makes its first appearance as a shallow groove, the epiblast extending the entire length of the embryo (Figs. 130 and 131). Its edges gradually coalesce to form a tube lined with epithelium, the neural tube. The ectoderm supplies all of the nervous elements of the spinal cord. The mesoblast intrudes itself between the neural tube and the overlying skin, completely surrounding the former, and gradually becomes transformed into the meninges, vertebrae, muscles and fibrous structures through a process of chondrification and ossification. Each vertebra has three centers of ossification, one for the body itself, and one for each half of the neural arch, the latter being formed by the fusion posteriorly in the median line of the two laminae arising from these separate centers of ossification. This union begins in the thoracic region and extends in both directions. Hence the frequency of defects in the lumbosacral and cervical regions where the closure is effected last. The absence of union or defective union of these elements forming the vertebral arches results in the bifid spine with its cleft affording opportunity for the protrusion of meninges alone or of meninges and cord. While the defect is most common in the posterior median line where fusion takes place, a lateral or anterior cleft is occasionally found.

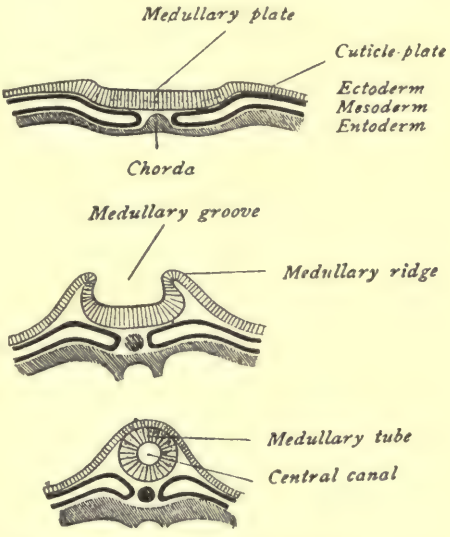

FIG. 130.—SCHEMATIC REPRESENTATION OF THE FORMATION OF THE MEDULLARY TUBE FROM THE OUTER GERM-LAYER. (Villiger.)

[1] For these statistics we are indebted to Dr. James A. Harrar, Surgeon to the New York Lying-in Hospital.

Defective closure of the vertebral column is almost invariably accompanied by a defect in the dura, although Hildebrand's investigations have shown that the dura is intact in many cases of meningoceles. The pia and arachnoid are seldom affected unless the spinal cord has failed to close; and, if the cord be intact, we usually find a complete epidermal covering in spite of vertebral and dural defects.

Pathogenesis.—Numerous theories have been propounded to account for the occurrence of spina bifida, but an entirely satisfactory explanation is still wanting in this as in many other congenital defects. It is difficult at the present time to determine the precise part played by heredity in the pathogenesis. The Report of the London Commission states that the "deformity occurred in three successive children in one family, and in another family in two successive children, the ninth and tenth." In one of Demme's cases the father was afflicted with talipes of congenital origin, and in two other cases the mother with hare-lip. In weighing the evidence in favor of the position of heredity as an etiological factor, although there are many instances of widespread maldevelopment, polydactylism, supernumerary mammary glands, congenital hydrocephalus and celft palate, still we cannot avoid the feeling that possibly we are dealing here more with coincidence than necessary premise. Unfortunately, medical literature, particularly in neurology, is replete with suggested etiology founded on very few reported cases. It seems that the less we know of the genesis of an abnormal condition, the longer becomes our list of possible causes. Therefore, let us admit the possibility of a lack in potential on the part of the blastodermic layers involved to follow con-

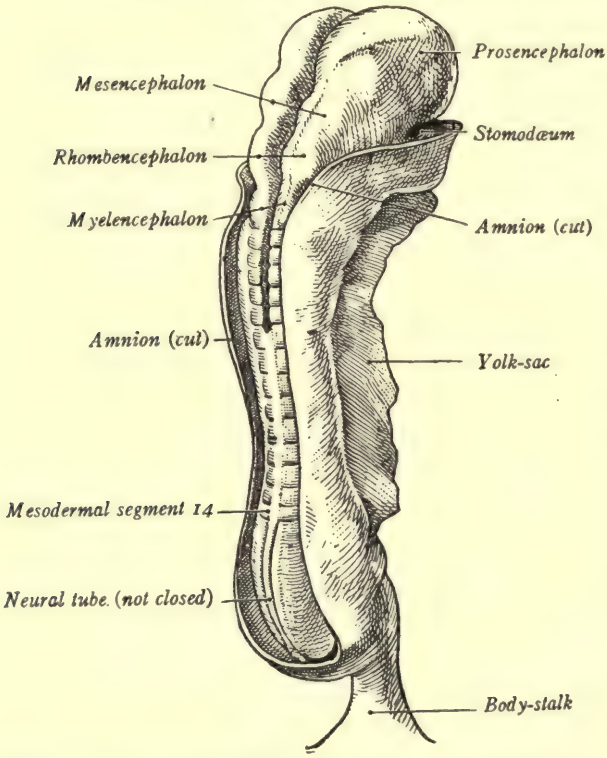

FIG. 131.—HUMAN EMBRYO OF 2.4 MM., SHOWING NEURAL TUBE CLOSING AND THE BRAIN VESICLES. (After Kollmann.)

ventional cleavage and union. If this be a pronounced and widespread weakness, we might postulate various types of maldevelopment in the same subject. Regarding the hereditary transmission of such lack of potential, the best we can do is to admit its possibility, though failing in its proof.

It is a well-known fact that very often in the mother or the child or both the Wassermann reaction is positive. Occasional cases are also reported with a history of tuberculosis in the family, as in Chambrelent's case in which the father had previously died of tuberculosis. In fact, tuberculosis is sometimes found in combination with spina bifida. Gordon reported such a case in which autopsy revealed a tuberculous meningitis and pulmonary tuberculosis; the mother yielded a positive Wassermann reaction. These are but a few instances, and many others might be cited in which the parent or parents have been the subjects of tuberculosis, syphilis, or both. Concerning tuberculosis, it may well be argued that it is of such common occurrence that one can hardly attach much significance to it as an etiological factor.

Uncertain as we are concerning heredity and infection as causative factors, we are little, if any, surer of those of a mechanical nature, in which, it seems to me, lies the crux of the situation. We have long since learned the futility of hoping for the permanent cure of a lesion, the fundamental cause of which is not understood. In the early part of the nineteenth century Meckel, Fleischmann and others attributed the anomaly to arrested development. Later some (Förster, Rokitansky, Ahlfeld) have looked upon the cystic tumor as the primary lesion, the pressure of the fluid within the meninges or within the central canal of the cord causing a cleft in the vertebral arches, through which the cystic tumor protrudes. This theory of "dropsy of the central nervous system" was soon superseded, however, by that of Cruveilhier, Virchow, Ranke and others, who attributed the abnormality to an imperfect separation of the cord and skin; and gradually arrested development came to be regarded as the principal etiological factor. Non-union of the vertebral arches was also attributed to the traction of amniotic bands. von Bergmann and von Recklinghausen were the first to suggest the possibility of two separate and disinct etiological factors, arrested development and an increased transudation of fluid from the vessels in the pia and arachnoid. These theories were advanced, of course, before our recent investigations on the origin of the cerebrospinal fluid. von Recklinghausen further suggested that disproportionate development between the cord and vertebral column might account for the protrusion of the cord in cases of syringomyelocele.

In the light of recent embryological and pathological research, there seems to be little doubt that arrested development of the vertebral arches and some or all of the neural contents of the canal is one of the causes, possibly even the prime cause, of spina bifida, but I cannot agree with

those who believe it to be the sole etiological factor. That it is responsible for the congenital defects in the vertebrae, in the meninges, and in the cord, is a fact which is scarcely open to question at the present day, particularly when we consider that other congenital defects due to maldevelopment, such as hare-lip and cleft palate, are often associated with spina bifida.

On the other hand, it seems highly improbable, if not impossible, that defective development alone should be responsible for the large hernial protrusion almost invariably present. To account for this phenomenon another factor must be at play. Why should it not be increased cerebrospinal pressure? The fact that hydrocephalus is so often associated with spina bifida or appears as a postoperative complication is strong corroborative evidence. That the balance between absorption and secretion of cerebrospinal fluid may be easily disturbed we have learned in our recent studies of the cerebrospinal fluid in many other conditions, such as tumors, meningitis and hydrocephalus. Whether the increased pressure be due to abnormal secretion on the part of the choroid plexus or delayed absorption or a combination of the two factors is a point which can only be determined after many painstaking investigations. But that increased cerebrospinal pressure is one of the factors responsible for the development of spina bifida is a fact which can no longer be overlooked either from the standpoint of pathogenesis or of treatment. Arrested development is responsible for one phase of the anomaly, increased cerebrospinal pressure for the other.

Course.—The clinical course of spina bifida and the expectation of life depend entirely upon the variety. The myelocystoceles and myelomeningoceles run a course inevitably and rapidly fatal; the meningocele, though its mortality is high, is not necessarily incompatible with growth and health, and in spina bifida occulta the lesion is often not discovered until adult age. The cystic variety, however, far outnumbers the occult type and the prognosis without intervention is exceedingly grave. At least 80 per cent die during the first year; of the 20 per cent remaining, over half die during the next three or four years, and of the surviving, the great majority are afflicted with serious physical infirmities of nervous origin. The Registrar General's Report shows that there were 89 deaths from spina bifida in London in 1882, and of this number 86 were under one year of age. In 32 of the 57 cases observed by Demme no operation was performed. The survival periods are shown in Table I, p. 273.

The mortality is greatest during the first month of life, and in most instances death is due to ulceration, to rupture of the sac or to septic meningitis, although hydrocephalus, other physical defects and malnutrition are responsible for a large number. In an exceedingly small number of cases the sac gradually shrinks and spontaneous cure results. The

TABLE I

11	died	between	the	8th and 14th day
9	"	"	"	15th and 22nd "
5	"	"	"	23rd and 30th "
3	"	"	"	3rd and 4th month
1	"	at		5 months
1	"	"		8 "
1	"	"		12 "
1	"	"		2 years

London Commission discovered 11 patients in good health at the ages of 9, 13, 13, 17, 23, 25, 25, 25, 32, 40 and 43. While in most cases the prognosis is exceedingly grave and the course short, there are a few instances, exceptions to be sure, in which the deformity is not incompatible either with life or with health. The following case recently came under my observation:

Spina bifida in a woman 37 years of age, the hernial protrusion having developed gradually after birth until it reached its maximum when the patient was fourteen. The most conspicuous features of the case were pyloric pain, irregular areas of paresthesia, hyperesthesia and tactile anesthesia over the buttocks and sacrum, and marked disturbance of motor function in the lower extremities.

The patient, a young woman, *aet.* 37, had suffered more or less discomfort and disability since birth. Her parents were not alive, but so far as could be ascertained, both pregnancy and labor were uncomplicated. At the time of birth there was a defect in the lumbosacral region, but no protrusion, the hernia having developed gradually after birth until it reached its maximum size when the patient was fourteen. The overlying skin was thick and warty with the exception of one place where it was extremely thin and easily ruptured. Up to the age of eleven there was a constant discharge from the swelling, but it had gradually become less free until at the time I saw her there was practically no leakage. No attempt had ever been made to reduce the hernia. At the age of twelve, the patient weighed 100 pounds and since that time she has gained rapidly, reaching a maximum of 285 pounds. She did not walk until the age of six, and then only with the aid of a wheel crutch. Three years before I saw her, she began to have her first attacks of pain in the lower pelvis, involving the vagina, urethra and bladder. This pain was induced by change of position, sitting up and walking, but disappeared entirely during her menstrual periods. In character it was like a dull ache, with occasional burning and smarting. There was also an area of paresthesia and hyperesthesia over the sacrum and buttocks, particularly on the left side.

Physical Examination.—*Sensory Disturbances.* On the right side there was analgesia and tactile anesthesia extending from the tumor to the gluteal fold, also an area of analgesia extending to the knee. There was an oval area of paresthesia reaching from the protrusion downward on the left side to a point seven or eight centimeters below the gluteal fold. Below this there was an ill-defined area of hypalgesia. Right lower extremity: From the foot up to the bend of the knee posteriorly there was complete analgesia and tactile anesthesia; anteriorly, begin-

ning at the inner aspect of the patella, there was a narrow band on the anterior and inner aspect of the leg extending downward ten or twelve centimeters where tactile sensation was preserved; with the exception of this area tactile sensation was lost on the anterior aspect below the knee. Above the knee there was no sensory disturbance with the exception of that noted above. Left lower extremity: The area of tactile sensation extended down to a line about five centimeters above the tip of the internal malleolus; below this point all sensation was lost. Pain sense ex-

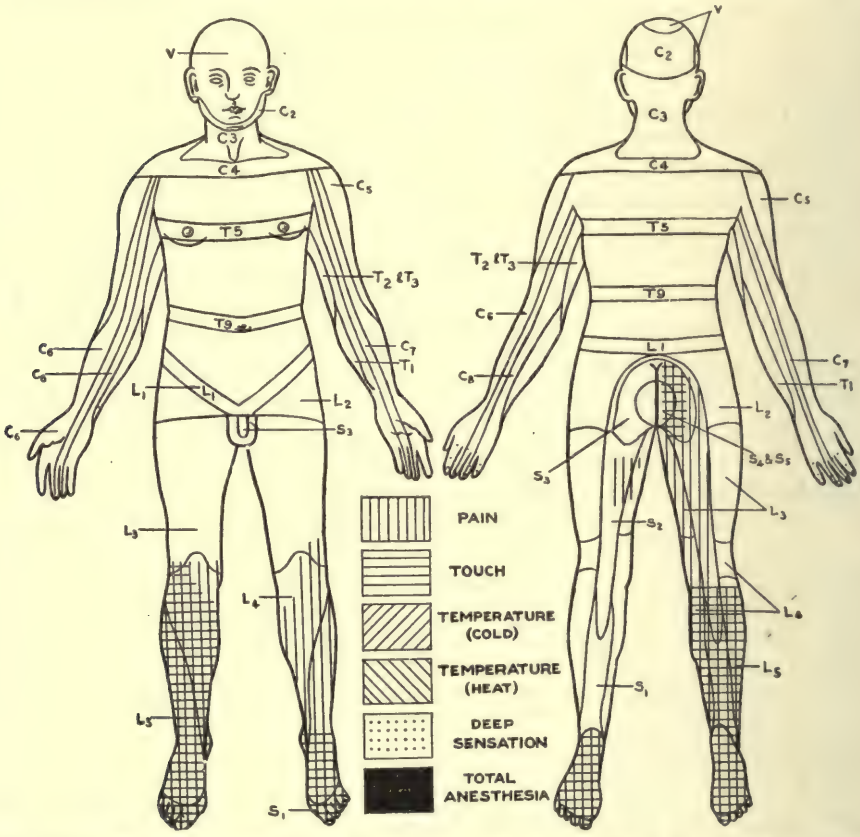

FIG. 132.—SENSORY DISTURBANCES IN A CASE OF SPINA BIFIDA IN AN ADULT. (*Vide* Fig. 133.)

tended down to a level two and a half centimeters above the upper margin of the patella with a narrow band extending down to the inner aspect of the leg. There was a zone five centimeters below this limit of pain sensation on which the answers were doubtful and conflicting. Perineum: There was no disturbance of sensation in the region of the anus (Fig. 132). *Motor Disturbances.* Right lower extremity: There were no movements of the toes or ankle; she could extend the leg on the thigh and flex the thigh on the abdomen, but could not flex the leg on the thigh. The power of external and internal rotation of the thigh was lost. There was slight power of abduction and marked power of adduction. Left lower extremity: Concerning motion of the toes and ankle as well as flexion and extension of the knee and hip joints, the condition was the same as in the right lower extremity.

Adduction and internal rotation were preserved, but the power of abduction and external rotation was lost. *Reflex Disturbances.* There was loss of patellar, tendo Achillis and plantar reflexes on each side.

There was a mass 5 cm. in diameter, projecting outward about 3 cm., the

FIG. 133.—SPINA BIFIDA IN A PATIENT THIRTY-SEVEN YEARS OF AGE.

integument of which was thickened and hard, like that of elephantiasis, with the exception of one place on the right aspect, where the skin was not so thick and there was a sense of fluid content (Fig. 133). Everywhere else the protrusion felt solid. There was no impulse on coughing, but pressure over the tumor elicited pain not only locally, but some distance up the spine.

Pathological Anatomy.—There are two anatomical anomalies to be considered in spina bifida: (1) the defective closure of some or all of the mesodermic elements and, in some types, of the ectodermic as well; (2) the hernial protrusion which takes place through the opening thus formed. If the medullary canal closes during fetal life, as it does in cases of meningocele and syringomyelocele, the epidermis also unites in spite of defects in some of the mesodermic elements. In such cases the pia and arachnoid are seldom involved, although a vertebral defect is almost invariably accompanied by a defect in the dura. On the other hand, when the neural tube fails to close in early embryonic life, as it does in cases of rachischisis and myelomeningocele, the epidermis is found to be lacking at the site of the lesion, a fact which contributes in no small degree to make these the most serious types with which we have to contend. In rachischisis, there is complete non-union of the medullary tube, which may extend the entire length of the cord (total rachischisis) or may be limited to a certain portion (partial rachischisis). In myelomeningocele we have the latter condition accompanied by a cystic protrusion. In other cases the cord reaches a later stage of development, but a cyst forms in the central ependymal canal and protrudes through the defect in the dura and vertebral arches (syringomyelocele). In meningocele and spina bifida occulta, we find the evolution of the cord has been completed, and arrest of development confined to the vertebrae and dura, or vertebrae alone. In the former variety, a cystic tumor forces itself through the vertebral defect, while in spina bifida occulta there is no protrusion, but merely a vertebral cleft. It should also be borne in mind that we sometimes find overlying the protrusion a solid tumor, most often a lipoma. While the skeletal defect is to be found usually in the vertebral arches, in certain instances the malformation is in the bodies of the vertebrae, and the cystic tumor protrudes into the pelvis or abdomen. The cleft in the neural arches varies greatly in size. In some true meningoceles, the cleft is very small; indeed, cases have been known in which the meningocele protruded between two normal arches, the opening becoming closed so that the sac no longer communicated with the subarachnoid space. As a general rule, however, the defect involves several vertebrae, usually the last lumbar and some or all of the sacral. Although the size of the hernial protrusion is often a criterion of the extent of the vertebral defect, this is not always the case. In one of the specimens examined by the London Commission, the defect involved the lowest four thoracic vertebrae and all the column below that point, while the protrusion never measured more than 5 cm. x 6 cm., and in some cases the hernia may be entirely lacking, as in the case illustrated in Plate VI.

In the natural sequence of embryonic development, spina bifida is most common in the lumbar and sacral regions, less in the cervical, and most rare in the thoracic region of the vertebral column. In most of my cases

PLATE VI.—SPINA BIFIDA WITH EXTENSIVE VERTEBRAL DEFECT, BUT NO HERNIAL PROTRUSION.

the defect has been in the lumbosacral region; there was, however, one in the cervical and one in the thoracic region. In 48 cases at the New York Lying-in Hospital in which the location was stated, 26 were lumbosacral, 10 sacral, 7 lumbar, 3 thoracicolumbar and 3 were total. Moore, in 1905, collected 385 cases distributed as follows:

TABLE II

Lumbar	34	per cent
Lumbosacral	29	" "
Sacral	23	" "
Cervical	9½	" "
Thoracic	4½	" "

The following table, compiled from the statistics of von Bergmann's Clinic, further bears out the truth of this statement:

TABLE III

Type	Cervical	Thoracic	Lumbar	Lumbosacral	Sacral	Total
Meningocele				1	4	5
Myelocystocele	4		9	8	3	24
Myelocele	1	9	11	9	4	34
Total	5	9	20	18	11	63

Passing to the consideration of the cystic tumor itself, we find that it varies in size from 3 cm. to 15 cm. or, to put it more graphically, from the size of a cherry to that of a child's head, and that it is soft and elastic in consistency so that upon palpation one may often detect the vertebral defect beneath it. These tumors, circular or ovoid in contour, are at first sessile, but as they increase in size they often become pedunculated; small tumors practically never have a pedicle. There are certain external characteristics which are peculiar to the individual types, as the hypertrichosis of the spina bifida occulta, and the three distinct zones of the myelomeningocele. The character of the external covering and wall of the sac depends entirely upon the variety of spina bifida. The wall of the sac may be composed of one or all of the meningeal membranes, or of the cord itself; even the nerve roots may be incorporated in the sac wall. Externally, it may be covered by skin with an underlying layer of fat, or by the membranes alone, which merge almost imperceptibly with the skin at the periphery of the tumor. Cases with a strictly normal cutaneous covering, however, are rare. It is much more usual to find a thin membrane-like tissue over the surface, often with signs of ulceration and of imminent rupture. Telangiectasis is one of the predominant characteristics of the myelomeningocele. The sac is always filled with cerebrospinal fluid, and in certain varieties it may be traversed by the nerve roots and cauda equina.

There has been much confusion as to the nomenclature for the various anatomical types of spina bifida, but the classification we have adopted is based upon the nature and location of the protruding tumor. Hence, we have first the division into posterior and anterior spina bifida, depending primarily upon whether the cleft and the hernial protrusion be on the posterior or anterior aspect of the column. Secondly, based upon the construction of the sac walls and upon the sac contents, there are four groups:

(1) *Meningocele* is a protrusion of the dura or both dura and arachnoid through a cleft in the vertebrae, the collection of fluid being in the subdural or subarachnoid space posterior to the cord.

(2) *Spina bifida occulta* is really a variety of meningocele, except that the hernial protrusion is either small and hidden, or entirely lacking, and, therefore, on account of its slow development and the latency of its symptoms, it demands special consideration in regard to both treatment and prognosis.

(3) *Meningomyelocele* is a protrusion of the defective cord and anterior portion of the pia through a cleft in the posterior portion of the vertebral column, dura, arachnoid and pia, the collection of fluid being almost invariably in the subarachnoid space, anterior to the cord.

(4) *Myelocystocele* or *syringomyelocele* is a protrusion of the membranes and the cord. In this variety, however, the collection of fluid is in the central canal of the cord, which is greatly distended; the cord substance is atrophied and forms the inner lining of the sac.

Meningocele.—This variety of spina bifida, characterized by a defect in the vertebrae or in the vertebrae and dura through which the membranes herniate, represents chronologically a later stage than the other types; the cord has attained complete evolution, the epidermis has closed, and the defect is limited to the vertebrae or vertebrae and dura (Fig. 134). Though the least grave form of spina bifida, it is unfortunately the most uncommon. It is more frequently seen in the sacral region, less often in the cervical, and rarely in the lumbar and thoracic. The walls of the sac may be composed of dura, of dura and arachnoid, or only of arachnoid, although in most cases the dura is included. It is often impossible, however, without careful microscopical examination, to ascertain whether one or both membranes are present in the sac. Hildebrand has reported several cases in which the dura was intact. With meningoceles situated in the upper segment of the vertebral canal, the fluid effusion shows a predilection for the subdural space, while in the lumbar and sacral segments it is almost invariably in the subarachnoid space. In the upper segment, the cord and nerve roots are almost never present in the sac, while in the lower segments the cauda equina is sometimes found adherent to the sac wall, and sometimes entirely free in the sac. The skin over the outer surface may be quite normal, attenuated, or thickened. Toward the summit of the tumor it invariably becomes thinner and at times approx-

imates the thinness of paper. By its translucency, underlying vessels may be plainly seen. Fluctuation is common to all, and the semipedunculated variety is freely movable. Superimposed upon the meningocele may be a solid tumor such as a lymphangioma, fibrolipoma, a dermoid cyst, or a

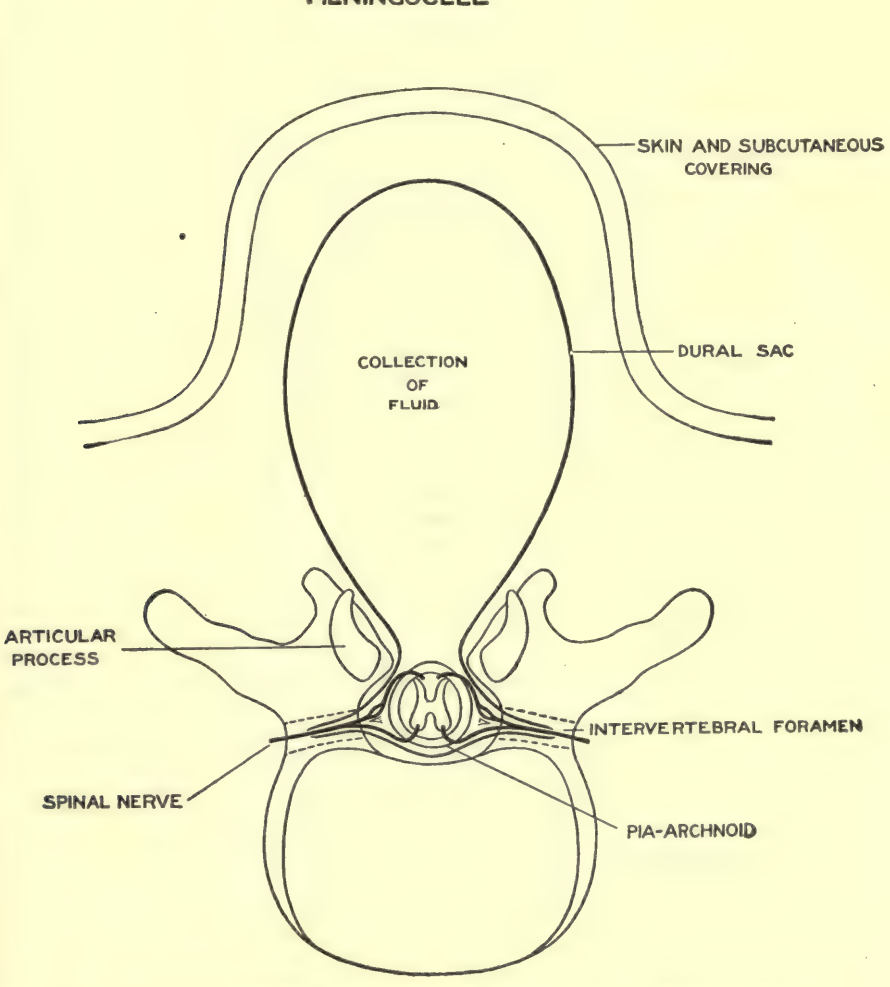

FIG. 134.—ANATOMICAL RELATIONS OF MENINGOCELE. (Diagrammatic.)

mixed tumor formed from remnants of mesodermic and ectodermic tissue. Sometimes the meningocele may be superimposed upon a myelocystocele.

SPINA BIFIDA OCCULTA.—Spina bifida occulta presents many of the characteristics of a true meningocele, but deserves special consideration because of peculiar anatomical features which render the clinical manifestations and the treatment of this anomaly quite different from the group

just considered. In spina bifida occulta, as in meningocele, the development of the spinal cord is complete and the epidermis closed; there is also a defect sometimes in one, sometimes in several, of the vertebral arches, but the hernial protrusion characteristic of other types is either entirely

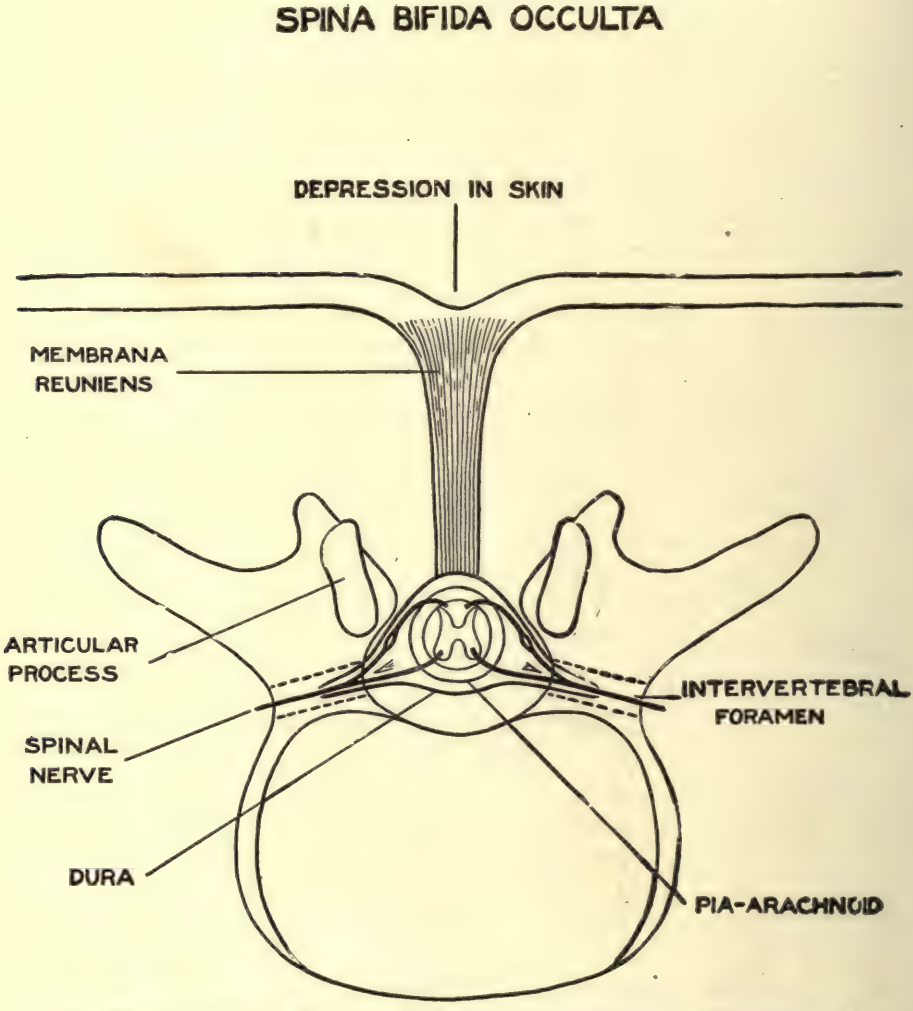

FIG. 135.—ANATOMICAL RELATIONS OF SPINA BIFIDA OCCULTA. (Diagrammatic.)

lacking or so small as to pass undetected. In this variety, however, the skin and spinal cord have never become completely separated; a firm fibrous band of connective tissue, fat, elastic fibers and striated muscular fibers, passes through the vertebral cleft and connects the cord with the

overlying skin (Fig. 135). As this band does not increase in size proportionately to the growth of the spinal cord and column, a time comes, usually between the tenth and twelfth years, the period of most active growth, when it begins to compress the roots and cord. The most conspicuous surface change is hypertrichosis (Fig. 136). The hair, which

FIG. 136.—HYPERTRICHOSIS IN CASE OF SPINA BIFIDA OCCULTA.

shows a tendency toward a concentric arrangement, varies in length, sometimes remaining short, and sometimes, after puberty, attaining a length of 25 or 30 cm. In addition to hypertrichosis one may find an indentation or fovea coccygea, more or less marked pigmentation of the skin over the defect, certain cicatricial changes and telangiectasis. In many cases the fibrous band entirely fills the vertebral cleft; in some, associated tumors may be present sometimes inside, sometimes outside, the vertebral column,

more particularly lipomata, fibromata, angiomata and dermoid cysts. Spina bifida occulta, like meningocele, shows a special predilection for the lumbosacral region, but occasionally the defect is discovered in the

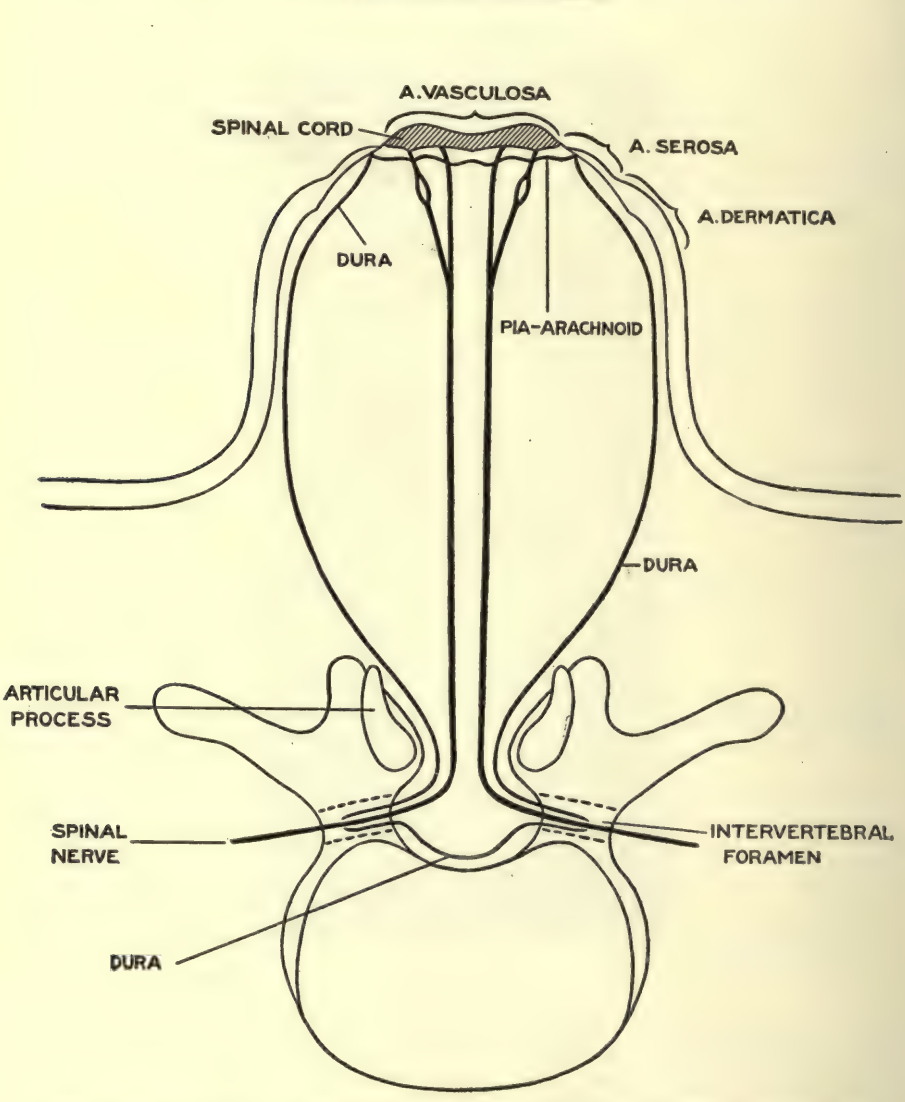

FIG. 137.—ANATOMICAL RELATIONS OF MYELOMENINGOCELE. (Diagrammatic.)

thoracic region, as in Reiner's case, in which a cleft of 4 to 5 cm. was found in the thoracic vertebrae.

MYELOMENINGOCELE OR MENINGOMYELOCELE.—In myelomeningocele

we have the gravest of all forms of spina bifida; not only the vertebrae, but the spinal cord with all its membranes and also the epidermis are involved. The developmental arrest occurs at an early period in fetal life, the posterior wall of the neural tube and the corresponding part of the meninges fail to close, and as a result there is a direct communication with the central canal of the cord. The fluid collects anteriorly to the cord, either between the anterior pia and anterior arachnoid, or within the arachnoid, and the cystic tumor thus formed protrudes itself through the vertebral defect (Fig. 137). The sac wall is composed of pia, and flattened against the dorsomedian surface is the inner surface of the cord or cauda equina and nerve-roots. As the cyst attains considerable size, becoming often as large as a child's head, the nerve-roots in the sac become elongated and subject to serious injury (Fig. 138).

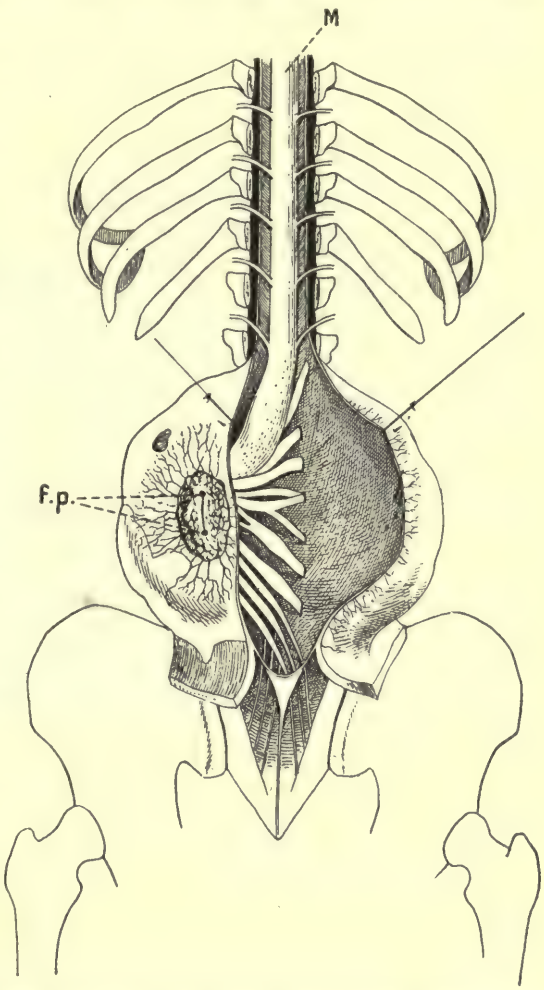

FIG. 138.—SAC OF MYELOMENINGOCELE OPENED TO SHOW THE DISPOSITION OF THE ROOTS. (After Cunéo and Veau.)

M, Posterior aspect of cord; F.p., polar foveolæ of the medullovascular area.

The characteristic feature of the myelomeningocele is the zone distribution on its outer surface. According to von Recklinghausen's description there are three distinct zones: the *zona dermatica,* the *zona epithelioserosa,* and the *area medullovasculosa,* but now more commonly known as the dermic, serous, and medullary zones. Surrounding the base of the cystic tumor is the zona dermatica or dermic zone, usually several centimeters in width, and composed of slightly inflamed, thickened skin with evidence of hypertrichosis and telangiectasis. At the edge of

this zone, epidermis, fascia, and posterior dura and arachnoid cease, the pia mater alone forming the outer covering of the sac. This zona epithelioserosa, or serous zone, forms the greater part of the outer surface of the sac. It is pink in color, tender, and so thin that the underlying capillary network is plainly visible. In the third zone, the area medullovasculosa, which is oval in shape and occupies the summit of the tumor, even the pia and the dorsal portion of the spinal cord are lacking. The

FIG. 139.—THREE ZONES IN A MYELOMENINGOCELE. (Bockenheimer.)

inner and ventral surface of the central canal of the cord, which forms this part of the sac, is covered with granulation tissue and numerous small vessels and is often ulcerated; along the summit of the tumor there is a groove indicating the attachment of the cord (Fig. 139).

The myelomeningocele is flat in contour, with a broad base, elastic in consistency and fluctuating. In most instances the cyst extends symmetrically on both sides of the median line. This type occurs most often in the lumbosacral region, less in the cervical, and very rarely in the sacral portion of the canal. It is unfortunate that it is more common than the other varieties of spina bifida in which the anatomical defects are not so grave. In the series of cases at the New York Lying-in Hos-

pital, 79 per cent were meningomyeloceles, and only 15 per cent simple meningoceles.

Syringomyelocele or Myelocystocele.—This type presents a defect in the posterior portion of the vertebral column and dura, but inasmuch as the arachnoid and pia are intact, and the cord and epidermis have closed, it is not so grave as the preceding variety. Here, however, the fluid effusion is not in the meninges, but in the central canal of the cord, which is greatly dilated by the fluid, a hernial protrusion being formed with the arachnoid and pia for its outer covering and a thin layer of medullary substance on its inner surface (Fig. 141). The cord is so compressed that in some places it is entirely lacking and the nerve-roots

Fig. 140.—Case of Spina Bifida. Meningomyelocele, with Abnormal Cutaneous Covering Similar to That of Elephantiasis.

are stretched, although not so often completely degenerated. The skin on the outer surface is slightly thickened at the base, somewhat hypertrichotic, with a tendency to lie in folds; it may also be scarred and present signs of telangiectasis. The tumor is usually round with a broad base, soft in consistency and fluctuates to such a degree that it is often possible to replace it completely within the spinal canal.

Spina Bifida Anterior.—While in most cases of spina bifida the vertebral defect is confined to the arches, in certain instances, the bodies of the vertebrae are affected, and through this opening the contents of the spinal canal extrude themselves anteriorly into the pelvic or abdominal cavity according to the location of the vertebral cleft; thus is formed, as Fairbairn described it, a cyst of the central nervous system simulating a pelvic or abdominal tumor. To this anomaly has been attached the term spina bifida anterior or meningocele sacralis anterior. It is exceedingly rare and is almost never correctly diagnosed *intra vitam,* inasmuch as it

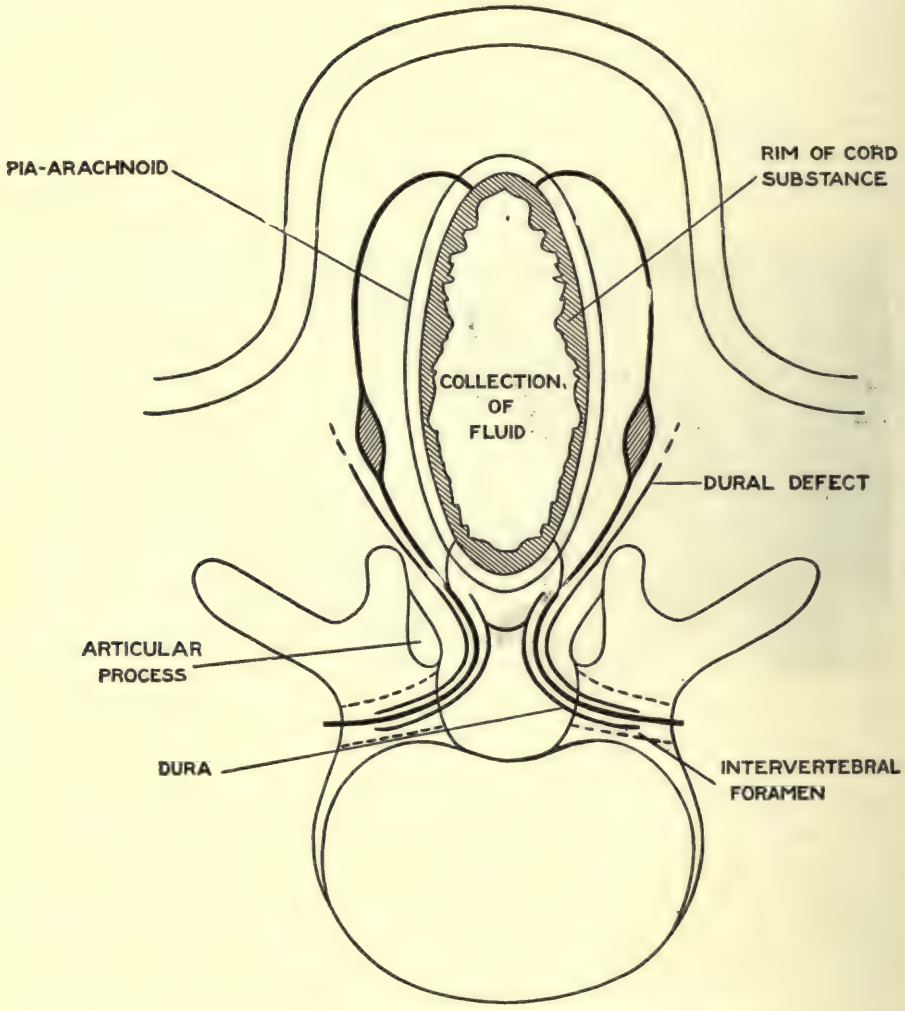

FIG. 141.—ANATOMICAL RELATIONS OF SYRINGOMYELOCELE.

simulates so closely a cyst of one of the pelvic or abdominal viscera that its true nature and its connection with the central nervous system is seldom discovered except on the operating table or at autopsy.

The bony cleft, varying in size from a small aperture to a large defect involving the bodies of several vertebrae, is most frequently in the sacral region, so that the protruding tumor naturally gravitates into the pelvis.

In some cases there is no real defect, the tumor protruding between two bodies. If, as in the case reported by Robinson, the defect be in the lumbar region, the hernia and its contents will be found within the abdominal cavity. This patient, a little girl of eleven months, had shown since birth some enlargement of the abdomen of increasing dimensions. It was evidently cystic, did not involve the bladder or rectum, and was thought to be a tumor of the broad ligament. In addition, the child had

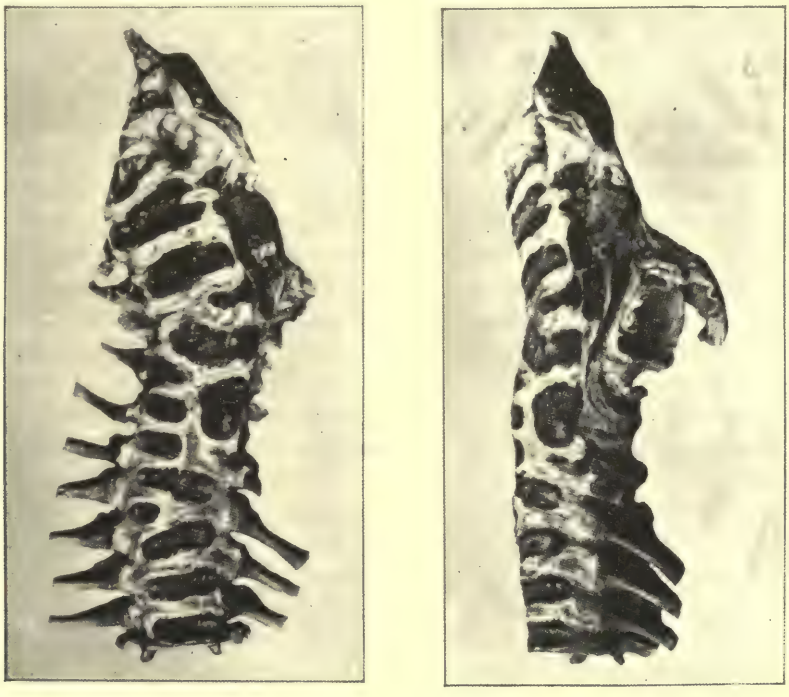

FIG. 142.—THE SPINE IN A CASE OF SPINA BIFIDA, SHOWING IRREGULAR FORMATION OF VERTEBRAE. (Robinson.)

A, anterior view; B, lateral view, showing the cavity of spina bifida.

a left talipes equinovarus and six toes on the left foot. On the operating table the cyst was tapped, a pint of clear, watery fluid withdrawn, and the cyst wall was found to be attached to the vertebral column just below the site of the transverse mesocolon. The defect in the vertebral column was readily felt, and the neck of the cyst ligated. The child died ten days later and at autopsy a defect on the right side of the column was found extending from the last thoracic vertebra and including all the lumbar vertebrae, the cyst protruding on a level with the first lumbar vertebra. "The bone defect in front is sharply defined by the lateral parts of the body centers; there are no pedicles or transverse processes, and only a small portion of the laminae persists closely adjacent to the

spinous processes. . . . The development of the bodies themselves is very irregular" (Fig. 142). The central canal of the cord was markedly dilated, but the cord did not form part of the sac wall, as it lay posterior to it, the nerves passing from the cord to the sac wall.

As in the posterior meningocele, the walls of the sac in the anterior variety are composed of some or all of the meningeal membranes; the sac contains cerebrospinal fluid in varying quantities, the largest amount three liters, as in the case reported by Kroner and Marchand. The cystic tumor is subject to the same variations in size as that of posterior spina bifida. In most of the reported cases it has been found to occupy the hollow of the sacrum, filling the pelvis, pushing the intestines to the side, and the uterus up into the abdomen.

Symptomatology.—The symptoms of spina bifida fall naturally into three divisions: first, the local symptoms due to the mere presence of the extraspinal cystic tumor; second, the nervous phenomena caused by compression or degeneration of the cord, cauda, or nerve-roots; and third, the symptoms due to associated malformations and defects. Sometimes, as in cases of pure meningocele, the local symptoms may be the only evidence of the anomaly, but in the more severe forms, in the myelomeningocele and syringomyelocele, all three groups are represented.

Of the size, form and external appearance of the hernial protrusion characteristic of all forms of spina bifida except the occult variety, enough has been said. Since the tumor is filled with cerebrospinal fluid and is in direct communication with the subarachnoid space, spinal and cerebral, its volume is variable. It may be influenced by the position of the patient, diminishing in size as the child is placed in the supine or head down posture; its volume increases during such expiratory acts as crying, laughing, or sneezing. On palpation the tumor yields more or less to pressure, depending upon the tension of the cerebrospinal fluid therein contained, according to whether the defect is large, small or obliterated; in the latter instance the tumor is quite unyielding. With a free communication into the spinal canal the fluid contents may be replaced within the canal, but, as this may excite convulsions or lead to coma, the practice is not justifiable and is entirely unnecessary for diagnostic purposes. The author witnessed a demonstration by a learned teacher and clinician where alarming symptoms of intracranial pressure developed after forcible reduction of the sac contents. Resuscitation was afterwards accomplished, but not without some difficulty and anxiety. The transparency of the tumor depends on the thickness of its walls. By transillumination one finds the tumor wall opaque or transparent. It is often possible, upon deep palpation, to feel the osseous defect beneath the hernia, and sometimes even the cord and roots.

Inasmuch as the spinal cord and roots are involved in all forms of spina bifida, excepting the simple meningocele, the *nervous phenomena*

play an important part in the clinical syndrome. They consist in motor, sensory and trophic disturbances, and vary according to the location of the anomaly and the intensity of the compression or degeneration of the medullary substance. They may be present at birth, may appear shortly after birth, or not until a later period, depending entirely upon the time and manner of the cord and root involvement. In cases of grave anomalies, however, it is usual to find the nervous phenomena present at birth, as here they are the expression of the arrested development of the nervous elements.

Of the medullary symptoms the motor phenomena are most pronounced, being present from birth in most instances, although they may not appear until later, as is frequently the case in spina bifida occulta. They manifest themselves usually in the form of complete paraplegia, with secondary contractures and paralysis of the bladder and rectum, and with the usual terminal atrophy similar to that resulting from infantile paralysis. Occasionally, the paralysis is limited to a certain group of muscles or to one lower extremity; or, it may be more pronounced in one extremity than the other. Talipes in one form or another, resulting from paralysis of the tibialis anticus and other muscles, is an almost invariable accompaniment (Fig. 143). The patellar reflexes may be weakened, and the Achilles reflexes are often absent. In rare instances, when the defect is situated in the cervical or thoracic region, there is a slight degree of spasticity in the lower limbs. The most peculiar feature in this entire group of symptoms is the fact that the upper extremities usually escape involvement, even when the anomaly is in the upper part of the canal. Since the motor roots suffer more severely from stretching and compression than the sensory roots, except possibly when the cauda is involved, the sensory phenomena are not so conspicuous. Nevertheless, in almost every case where cord and roots are involved we find sensory disorders in the form of areas of anesthesia, analgesia, hyperesthesia and, occasionally, neuralgia. These areas of sensory disturbance are more or less extensive, but are almost invariably limited to the lower extremities. Trophic disturbances may be a particularly grave feature, manifesting themselves in decubitus, muscular atrophy, desquamation, leiodermia and perforating ulcers, prone to develop on the feet or on the surface of the tumor.

In addition to the tumor and the nervous disorders, we find various *congenital defects* and *malformations*. Occasionally, two varieties of spina bifida may be combined in the same case, or there may be, in addition to the spina bifida, absence or malformation of other vertebral bodies resulting in scoliosis, kyphosis or lordosis. These deformities of the vertebral column vary greatly in degree. Plagemann has recently reported a case of spina bifida in the thoracicolumbar region in which the accompanying lordosis was so severe that it was possible to feel the third lumbar vertebra

under the skin of the abdomen, and when the child was in a sitting position the costal arches and abdomen rested on the thighs. It is not at all uncommon to find congenital lesions or defects in other parts of the nervous system; for example, hydrocephalus (Fig. 144) is a prominent feature in

FIG. 143.—PHOTOGRAPH OF CHILD WITH SPINA BIFIDA, SHOWING MARKED TOE-DROP IN LEFT FOOT.

many cases of spina bifida, while anencephalus, absence of the cerebellum, diastematomyelia, atelomyelia and gliosis or syringomyelia are occasionally found. A primary hydrocephalus was observed at birth in 23 out of 68 cases at the New York Lying-in Hospital. Indeed, hydrocephalus may be said to be the predominant feature in many cases of

spina bifida, as it was in a case upon which I operated about seven years ago.

Spina bifida and increasing hydrocephalus in a child fourteen weeks old. At operation the meningocele, which was situated in the upper cervical region, was ligated after the removal of a superimposed benign tumor. The general condition of the child has since been good and at the age of five he was beginning to learn his letters.

FIG. 144.—STILL-BORN CHILD WITH MENINGOMYELOCELE IN THE LUMBOSACRAL REGION; LARGE HYDROCEPHALUS. (From the New York Lying-in Hospital Museum.)

The patient, *aet.* 14 weeks, was admitted to my service at the University Hospital March 10, 1910 (File No. 6259). There had been a non-instrumental delivery and full term labor, but at birth the child presented a small swelling on the back of the neck which had been gradually increasing in size. The child appeared to be in excellent health, weighing 17 pounds upon admission. The heart, lungs, abdomen and extremities were normal, and its general nutrition was unusually good. The child presented, however, a moderate hydrocephalus, which was becoming more marked, and on the back of the neck just below the occipital protuberance there was a soft, fluctuating tumor about the size of a hen's egg (Fig. 145).

Operation, March 11, 1910. Under ether anesthesia a circular incision was made around the base of the protrusion. Superimposed upon the meningocele was a benign tumor, which had to be excised before the sac could be exposed. The latter was of small dimensions, pedunculated, and contained only cerobrospinal fluid. The

FIG. 145.—MENINGOCELE IN THE CERVICAL REGION.

pedicle was ligated and the wound closed with silk sutures. In this case the congenital defect in the vertebra was so small as to be practically a negligible quantity and required no plastic operation for its closure.

The postoperative convalescence was uneventful and upon the date of discharge, March 30, 1910, the circumference of the head was 46 cm. At an examination November 16, 1914, almost five years later, the head measured 60 cm., the fontanels were closed, and there was a slight strabismus. The general condition of the child was excellent, his nervous equilibrium much more stable; he could count up to ten, and was beginning to learn his letters.

Defects and deformities in other and quite remote parts of the body are not unusual, and among these may be numbered congenital luxation of the hip, syndactylia, polydactylia, polymastia, deformities of the lower extremities which are not caused by nerve involvement, absence of ribs, umbilical or inguinal hernia, prolapse of the rectum, uterus and other organs, defects of the intestinal tract, ectopia vesicae, diverticulum of the bladder and the like (Fig. 146). In a case of spina bifida recently observed by Mucharinsky there were two diverticula of the bladder.

The following tabulation compiled from the statistics of the London Commission and from Demme's cases shows the relative frequency of the various complications:

Complications	London Commission	Demme
Paralysis	53	Not stated
Talipes	42	13
Hydrocephalus	30	17
Idiocy	2	Not stated
Cretinism	1	" "
Curvature of spine	2	" "
Absence of cerebellum	1	" "
Hare-lip	0	3
Cleft palate	1	Not stated
Imperforate anus	1	" "
Ectopia vesicae	0	1

Moore, in his collection of 385 cases, found complications in 23 per cent which were fairly evenly divided between paralysis, talipes and

FIG. 146.—LARGE LUMBOSACRAL MENINGOCELE, COMPLICATED BY TALIPES, CONGENITAL DISLOCATION OF THE LEFT HIP AND GASTROSCHISIS. (From the New York Lying-in Hospital Museum.)

hydrocephalus, in many cases all of these complications being present.

These phenomena and anomalies, thus briefly sketched, comprise the predominant clinical features of spina bifida, but it must be remembered

that the clinical picture varies according to the type and with respect to cord and root involvement.

Meningocele.—Since neither cord nor roots are seriously involved in cases of pure meningocele, there are no symptoms other than the presence of a tumor with its characteristic features. In rare instances, there may be a slight degree of paralysis of the musculature of the pelvic floor, or a small area of anesthesia in the region of the anus. As a rule, however, motor and sensory disturbances, as well as associated malformations, are lacking, as in the following case upon which I operated two years ago:

Spina bifida in a child one month old. The meningocele, which was about the size of an egg and situated at the end of the spine, was opened, the cauda equina contained therein restored to its normal relations and the sac amputated. The child made a good recovery, and there was no recurrence of the swelling and no hydrocephalus during the two years following the operation, although a slight talipes varus developed.

The patient, *aet.* one month, was admitted to my service at the Episcopal Hospital, September 16, 1913 (File No. 3639). Her father and mother were both in good health. Labor had been difficult, but non-instrumental, and the baby appeared to be well-nourished and growing normally. There was a swelling at the end of the spine about the size of an egg which was then stationary. The heart, chest and lungs were normal, and there was no paralysis of the extremities or other anom alies or defects.

Operation, September 28, 1913. By the reflection of a cutaneous flap the meningocele was exposed and opened on its lateral aspect. Its contents were found to be the cauda equina, the termination of which was attached to the sac wall. These attachments were freed and the cauda restored to the vertebral canal. The sac, including its neck, was carefully isolated from the surrounding structures up to and well within the margins of the vertebral defect. The sac was then amputated, the neck closed, and the defect repaired with muscles and aponeurosis. Lateral muscular incisions were made on either side so that the erector spinae might be transferred to the median line, and this muscular layer was fortified with flaps from the aponeurosis. After the removal of redundant skin, the cutaneous wound was closed with a subcuticular suture.

The patient was discharged from the hospital ten days after the operation with the wound entirely closed. At a subsequent examination a year and a half later, the following notes were made: There had been no recurrence of the swelling and no hydrocephalus, but a slight talipes varus had developed in each foot which was readily corrected by a brace. There were no other deformities. The child's physical condition was excellent and there were no signs of mental retardation. A trophic ulcer of irregular dimensions, in the territory of the fifth sacral, that is in the sulcus between the buttocks, appeared one year after the operation (Fig. 147).

Spina Bifida Occulta.—In addition to the external changes at the site of the defect, such as hypertrichosis, pigmentation, telangiectasis, and a more or less marked depression in the skin, spina bifida occulta often

causes nervous disorders, which are occasionally present at birth, but more often do not appear until some time between the tenth and twentieth years, when the membranous band between the cord and epidermis begins to compress or pull upon the cord and roots. These nervous phenomena consist of motor, sensory and trophic disturbances of the lower extremities and paralysis of the bladder and rectum. Thus, we find a complete or partial paraplegia, accompanied almost invariably by paralytic club foot.

FIG. 147.—RESULT THREE YEARS AFTER RADICAL OPERATION FOR LUMBAR MENINGOCELE.
Note trophic ulcer of two years' duration in midline between nates.

areas of anesthesia, paresthesia or analgesia in the lower extremities, severe pains in the back and legs and neuroparalytic ulcers on the feet and legs. There is often a congenital weakness of the lower extremities, one or both of which may be retarded in development and become atrophied in later life. Defects and malformation of other parts of the body are especially common with spina bifida occulta. In this connection may be mentioned congenital luxation of the hip, syndactylia, scoliosis and umbilical and inguinal hernia. Pfanner has recently reported a case of spina bifida occulta associated with diverticulum of the bladder and incomplete urachus fistula.

It is quite possible that a spina bifida occulta may pass unrecognized because of the absence of external signs or of pressure symptoms. The external signs, such as hypertrichosis, are not an unfailing guide. Sometimes they are lacking, and again they may be present when there is no spina bifida. Thus, the incidence of spina bifida occulta is difficult to estimate. In fact, it is probable that many cases are overlooked, and that spina bifida occulta is much more frequent than is ordinarily supposed. In many cases there are no positive manifestations of the defect, excepting the hypertrichosis, until puberty, when in a previously normal child there may appear paralysis of the lower extremities, weakness of the sphincters, bilateral pes equinus, and severe pains in the back and legs. This is to be accounted for by the fact that the fibrous band passing through the cleft and connecting the overlying skin with the cord presses the cord against the opening. It is well to emphasize the fact that the mechanics of the disturbance caused by these bands must primarily be recognized as traction with or without torsion. Many authorities who speak of pressure symptoms do not make it clear that the pressure is secondary to this traction and at the margin of the abnormal opening in the canal. The growth of the band is not proportionate to the growth of the cord, and the discrepancy is greatest at the period of maximum growth from the tenth to the twentieth year; hence, the symptoms either appear then for the first time, or become more pronounced, if they have existed before. Whenever there is the slightest suspicion of a vertebral defect, whenever there are motor or sensory disturbances of the lower extremities or of the bladder and rectum not otherwise accounted for, roentgenological studies of the vertebral column should be made in order to determine the presence or absence of spina bifida.

Meningomyelocele.—In meningomyelocele, as we have already observed, the anatomical defects are much more grave, the clinical picture more complicated and the situation more serious. The nutrition of the child is very much below par, and its resistance at a low ebb. Grave nervous disorders in the form of motor, sensory and trophic disturbances are almost invariably present, and, as the anterior roots are more severely traumatized than the posterior, paralyses of the lower extremities and of the bladder and rectum constitute the dominant features. Indeed, total paraplegia with complete loss of control of the bladder and rectum, is not unusual in myelomeningocele. The upper extremities are sometimes paralyzed in those rare cases in which the defect is situated in the upper part of the column. Talipes is present whenever the defect be so located that the fourth and fifth lumbar and first and second sacral roots are injured; and, as myelomeningocele occurs most often in the lumbosacral region, talipes is one of the most constant manifestations. Sensory disturbances in the form of areas of anesthesia and hyperesthesia are often present, but much less marked than the motor phenomena. The gravity

of the picture is further heightened by the presence of trophoneurotic disturbances, principally ulcers, decubitus and, in some cases, a more or less extensive eczema. As in other types, there are the associated defects and anomalies, including, among others, hydrocephalus, ectopia vesicae, umbilical hernia and prolapse of the rectum or uterus.

Syringomyelocele or Myelocystocele.—Syringomyelocele, likewise, is a grave form of spina bifida, but, with the fluid within the cord instead of between the membranes anterior to it, the clinical picture differs in certain respects from that of myelomeningocele. In the first place, the children are constitutionally stronger; the skin over the defect is closed, rupture and ulceration are not so imminent and complete paraplegia is not so common, since the anterior roots, being outside the sac, usually escape damage. Motor disturbances are often limited to a unilateral talipes of one form or another, unilateral because the vertebral defect in syringomyelocele often involves only one side of the column. Isolated paralysis of the bladder and rectum is common with this variety, particularly if the lesion be just above the vesical and rectal centers in the conus; by the downward pressure of the fluid in the central canal upon the conus these centers are injured. Sensory disturbances, not so important a feature of myelomeningocele, are here more constant and more pronounced, since the accumulation of fluid within the cord compresses the sensory roots and their corresponding segments in the cord. Trophic disturbances play an important part here, as they do in myelomeningocele. Of the associated deformities and malformations, hydrocephalus is very common; appearing shortly after birth, it soon attains enormous proportions and brings with it all the signs of increased intracranial tension.

Spina Bifida Anterior.—In spina bifida anterior the cystic tumor protrudes into the pelvic or abdominal cavity. Hence, the picture is strikingly different from that of any of the posterior varieties. In some instances, spina bifida anterior is first suspected by the appearance of a tumor; in others, by the development of symptoms similar to those of pelvic or abdominal tumors. Severe abdominal pains associated with backache and headache are the predominating features in most cases, as in those of Fairbairn, Kroner and Marchand and others; occasionally there is obstinate constipation, as in Sawicki's case, or a chronic ileus, as in a case reported by Tilp; or it may be discovered by some accidental complication, such as obstruction to labor (Lohlein's case reported by Grossmann).

The various malformations and defects accompanying the other types of spina bifida are often found associated with spina bifida anterior. In addition to the anomalies already mentioned, however, defects of the internal organs are especially prone to occur in conjunction with spina bifida anterior. Robinson found one kidney bilobed; in Neugebauer's

case a uterus didelphys and vagina duplex were discovered; and Kroner and Marchand have reported a case of spina bifida anterior associated with bicornuate uterus and dilatation of the ureters.

Anterior spina bifida in a young woman twenty years of age. The cystic tumor which protruded into the abdomen was opened and drained. At autopsy it was found that the cyst which was attached to the right wall of the pelvis and sacrum was accompanied by a bicornuate uterus and dilatation of the ureters.

The patient, a young woman, *aet.* 20, had a right sided club foot and a slight weakness in the right leg, but no other demonstrable abnormality until four months previous to her admission to the Breslau Klinik, when she had a fall and a swelling appeared in the abdomen, accompanied by pain, backache, right sided headache and vomiting. A cystic tumor could be felt in the abdomen, extending on the left to the umbilicus and on the right to the costal margin, the vagina and uterus being pushed out of place by the cyst. The tumor was tapped through the vagina and 3,000 c.c. of a clear fluid withdrawn, but it refilled so rapidly that in three days it reached the umbilicus again. Pains continued to be so severe that the cyst was opened and drained. The patient's condition grew worse, and she died one month after the first puncture. The autopsy revealed a cyst attached to the right wall of the pelvis and sacrum in front of the right broad ligament and right tube. The uterus was bicornuate; there was some hydronephrosis and both ureters were dilated. There was a narrow opening just below the first sacral vertebra, and a cross section demonstrated that this opening ran obliquely through the sacrum and was a continuation of the dural canal. The conus medullaris reached to the second sacral vertebra, and the filum terminale ended in very dense tissue at the lower end of the canal. The entire lower portion of the sacrum and coccyx were very irregular in contour. There was a large cleft in the second sacral vertebra on the right side, and the first sacral vertebra was split into two parts. The cyst walls, which were 2 to 3 mm. thick, proved microscopically to be a continuation of the dura mater, although they were softer than normal dura and contained more blood vessels and cells. The fluid contents proved to be cerebrospinal fluid; hence, the lesion was a true spina bifida anterior (Fig. 148).

Diagnosis.—The diagnosis of spina bifida, with the possible exception of the occult variety, in which there is no hernial protrusion, and of spina bifida anterior, in which the hernial protrusion is within the abdomen, is comparatively simple. Nevertheless, even those forms of spina bifida with a definite posterior hernial protrusion may so closely simulate certain other conditions, particularly postrectal dermoids, sacrococcygeal teratomata, ischiatic hernias and lipomata of the sacral region, that considerable difficulty is sometimes encountered. However, when confronted with a hernial protrusion, congenital in origin, rapid in evolution, situated invariably in the median line and mostly in the lumbar or sacral region, occasionally at a higher level, round or oval in contour, soft in consistency, fluctuating and sometimes reducible, with a bony cleft palpable at the tumor's base, there can be little doubt that we are dealing with one of

the varieties of spina bifida. In those cases in which palpation fails to reveal the vertebral cleft beneath the tumor, the roentgenogram may confirm the diagnosis. Furthermore, since in spina bifida the sac is always filled with cerebrospinal fluid and is in direct communication with the

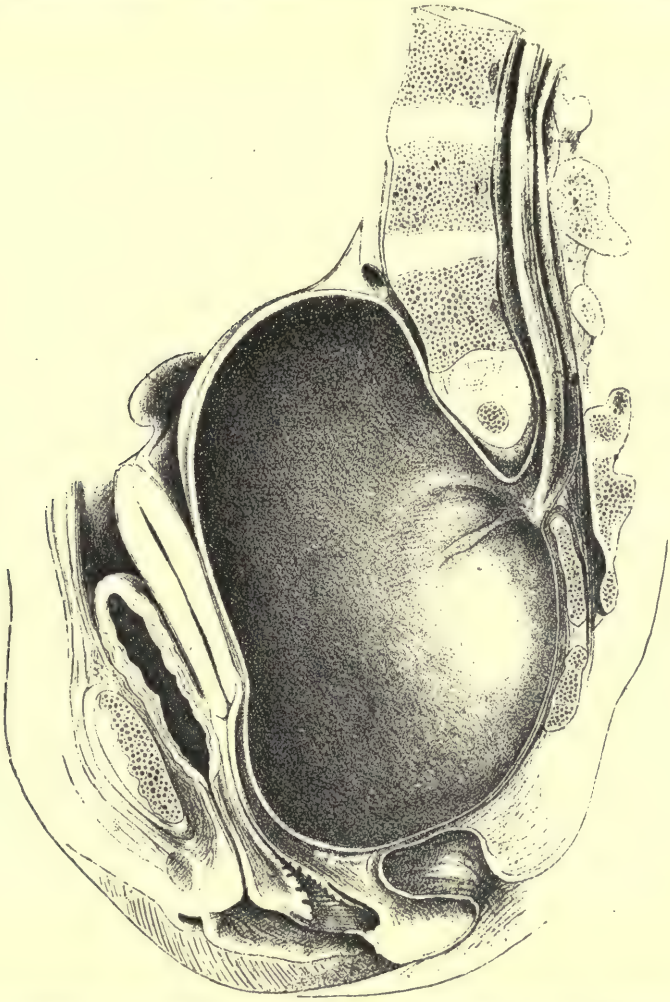

FIG. 148.—PHOTOGRAPH SHOWING SAC AND DEFECTS IN VERTEBRAE IN CASE OF ANTERIOR SPINA BIFIDA. (Kroner and Marchand.)

subdural or subarachnoid space, pressure upon the sac will cause bulging of the fontanels. The tension of the sac varies frequently with such expiratory acts as crying, coughing and sneezing, although this is not an absolute test, inasmuch as the volume of the sac may not be augmented by an increase in cerebrospinal pressure, if the vertebral defect be so small that the communication between the interior of the sac and the

subarachnoid space has become obliterated, as it does in some cases of simple meningocele. In cases of complicated spina bifida, transillumination should reveal the presence of roots or nerve fibers within the sac. Dermoid cysts are more apt to develop at the end of the coccyx, and, like other congenital tumors, are slow in evolution and may not manifest themselves until maturity. In addition to these characteristic and typical physical marks, there are not only the nervous phenomena, but the associated deformities and defects.

The diagnosis in cases of spina bifida occulta is more difficult, but hypertrichosis, pigmentation, telangiectasis and the slight indentation, if present, admit of but one interpretation. The roentgenogram may be helpful and the appearance of motor, sensory and trophic disturbances between the tenth and fifteenth years, otherwise unaccounted for, should arouse our suspicion.

The greatest difficulty from the diagnostic standpoint is with anterior spina bifida, which is seldom correctly diagnosed *intra vitam;* mistaken perhaps for a congenital tumor of one of the genital organs or for an abdominal lesion, the true nature of the condition is revealed only at autopsy, or at an exploratory operation. The x-ray should be of even greater value in confirming a preliminary diagnosis than in the posterior type. This was illustrated in a case which was recently under the care of Dr. Howard A. Kelly.

A case of anterior spina bifida in which the condition was diagnosed intra vitam with the aid of the roentgenogram.

The patient, a woman, *aet.* 52, had been in good health up to the age of ten, when she began to be troubled with increasing constipation until result could be obtained only by enema. Two years before coming under Dr. Kelly's care, she began to have to strain to void urine and had no inclination to void; one year before she began to have a sensation of numbness in the left pelvis and buttocks and a hysterectomy was performed, but it gave no relief and incontinence of the bladder appeared very soon. Dr. Kelly's examination showed that the reflexes were a little exaggerated, that there was anesthesia in the lower sacral segment which occupied an area above the coccyx. There was a sacral tumor beginning on the anterior face of the sacrum 7 cm. above the anal orifice. The tumor appeared to be round and elastic, extending one-third across the pelvis toward the pubis and involving the whole breadth of the sacrum. Pressure over the sacrum caused pain, but there was no kyphosis or other spinal deformity. Indeed, by palpation through the skin no defect could be felt, but with the finger in the rectum pressing against the tumor the sacral hiatus could be outlined by gently tapping over the skin of the back and securing a sense of fluctuation through the tumor. The roentgenogram further confirmed the diagnosis (Fig. 149). This is one of the very few cases which has been diagnosed during life.

Sawicki has recently operated upon a case of spina bifida anterior in which the preoperative diagnosis rested between dermoid cyst and a

sacral meningocele anterior. At the operation a tumor was found adherent to the anus and a second tumor communicating with the spinal canal, which proved to be an anterior meningocele. In this case, as in many others, there was not a sign of nervous or meningeal disturbance. The symptoms were chiefly those of intestinal obstruction. Hence, whenever the symptoms point to a tumor in the lumbar or lumbosacral region, the

Fig. 149.—Roentgenogram Showing Anterior Defect in Case of Spina Bifida Anterior. (Kelly.)

possibility of an anterior spina bifida must be borne in mind, even though nervous phenomena may be lacking. While by no means a common lesion, it is of more frequent occurrence than was previously supposed.

Differential Diagnosis.—While each variety of spina bifida has certain definite and well-marked characteristics, nevertheless there is some overlapping of types and differentiation is not always possible. The differential diagnosis is naturally limited to the three varieties with a definite posterior hernial protrusion, the meningocele, the myelomeningocele and the syringomyelocele, as spina bifida occulta or spina bifida

anterior could scarcely be confused with these more common varieties. The myelomeningocele should be readily recognized by its three concentric zones, especially by the dark red zona medullovasculosa in the center, unless these zones have been obliterated by an inflammatory process or by ulceration to such an extent as to simulate syringomyelocele. In complications such as these we must rely upon other means of differentiation. In myelomeningocele the paralysis is more extensive and complete, involving both lower extremities, and other deformities are also more often associated with it.

Much ingenuity is required in certain instances to differentiate between meningoceles and syringomyeloceles, since in both of these varieties the skin is intact and outwardly the appearance is quite similar. If the sac have a decided pedicle, it is safe to presuppose that it contains no nervous elements; if, on the other hand, it be umbilicated, this suggests the adherence of nerve fibers to the sac wall. Artificial illumination is sometimes a help if the outer coverings be not too thick. The size and location of the vertebral defect is a further aid, inasmuch as the vertebral cleft of the meningocele is small and mostly in the sacral region, while in syringomyelocele the defect is larger and may be found at any level. Pressure upon the tumor is followed more quickly by swelling of the fontanels in syringomyelocele; true meningoceles are seldom accompanied by any symptoms other than the local manifestations of the defect; associated with syringomyelocele may be telangiectasis, hydrocephalus, sensory, motor and trophic disturbances of the lower extremities and paralysis of the bladder and rectum.

Treatment.—The selection of cases for operation is a matter of prime consideration. In the final analysis it will be found that the majority of cases are unsuitable for operative intervention, not because of any technical difficulties in the closure of the defect in a very large percentage, but because of the associated paralysis and other complications that may be wholly uninfluenced by the operation.

A much disputed question is the age at which the operation should be performed. I entertain no radical views, agreeing neither with those who go to one extreme nor those who go to the other, with those who recommend operation in the first six months, or with those who advocate waiting until after the fifth year. The crux of the situation is this: Eighty per cent of the spina bifida babies die in the first year of various causes—marasmus, coincident infections, intercurrent diseases and meningitis. What proportion of this eighty per cent could be saved by early operative intervention? Probably very few except those who died from meningitis as a result of rupture of the sac. Threatening rupture of the sac in otherwise suitable cases is, therefore, a positive indication for operation during the first year of the child's life. With

this exception, operation should be deferred until after the first year, and even then resorted to only in a carefully selected group.

Contra-indications are four in number: hydrocephalus, irreparable deformities, paralysis of the sphincters and complete paraplegia. *Hydrocephalus* is considered a contra-indication by the vast majority, including Oppenheim, Broca, Schede, Patterson, Potheral, Muscatello and Henle. The relation between hydrocephalus and spina bifida has been dealt with both as an associated condition and as a sequel of operations for spina bifida. The postoperative prognosis in cases of spina bifida with hydrocephalus is always unfavorable and the development of hydrocephalus after operation is a not uncommon sequel. The suggestion has been made that before operation the effect of closure of the sac upon the intracranial volume may be determined by attempting to empty the sac by pressure, and noting the increase in pressure of the fontanels. Such a test as this, however, would be extremely misleading as taking into consideration only certain given physical conditions, such as increase in volume of fluid and diminution of space, and leaving out of consideration the more important physiological problem of the disturbance of the secretory and absorptive balance. Therefore, until there is a more hopeful means of dealing with hydrocephalus, we should not resort to the repair of spina bifida defects when hydrocephalus is a complication. In this connection mention should be made of Kauch's experience in a case of spina bifida complicated with hydrocephalus. When repairing the defect the subdural space was drained into the subcutaneous tissues with a tube 3 cm. long and ½ cm. in diameter. Two and a half years after, the child was reported as healthy and normally developed. This case is mentioned, not in any way to modify our attitude toward hydrocephalus as a complication, but merely to emphasize the necessity of having to reckon with hydrocephalus when considering an operation upon spina bifida.

All the associated *deformities* and *anatomical defects* of a serious nature, including diastematomyelia, atelomyelia, gliosis of the cord and ectopia vesicae, should be numbered among the contraindications.

Complete paraplegia with or without control of the sphincters is very properly regarded as a contraindication. "Such children," says Hildebrand, "should be left alone and should be allowed to die; in fact, the sooner they die the better." "Is it anything to boast of," he adds, "if two or more years after an alleged successful operation the child is reported as wearing a brace for the support of both lower extremities, and has incontinence with paralysis of bladder and rectum?" In these cases of complete paralysis the lesion is usually a complicated one (a myelomeningocele or myelocystocele), and not a simple meningocele. There is, in other words, a neuro-anatomical defect, which cannot be influenced by any operation designed merely to repair the skeletal defect. Moderate grades of paralysis, that is, partial paralysis of the extremities, or even

of the bladder, on the other hand, are not prohibitive of operation. In fact, in a number of instances the paralyses have, to a greater or less degree, been relieved by the operation.

As TEMPORARY CONTRA-INDICATIONS are included ulcerative processes in the neighborhood of the spina bifida. It would be quite impossible to maintain asepsis while these were present, and if operation be contemplated, it should be deferred until the ulcers have healed and the operation may be performed with skin intact. Exceptions might be made such as the presence of small ulcers which could be mechanically sealed and removed with redundant skin. But even here the surrounding lymphatics are charged with drainage material from the ulcer base, and wound infection cannot be avoided.

Looking the situation squarely in the face, the advantage of operation in the treatment of spina bifida lies chiefly in the fact that it lessens the incidence of meningitis. To be sure, the child's parents may desire an operation for the repair of a deformity, unsightly and unpleasant in their eyes, so that the operation may be said to have its esthetic side. But the number of cases of complete recovery are too small and the amount of relief too slight to look upon operation either as a means of preventing paralysis, or, if paralysis be present, of relieving it. The exceptions to the rule do not prove it.

MENINGOCELE.—With these preliminary remarks special consideration may be given to individual types. The first, meningocele, is patently the most favorable for operation, because, as compared with others, the myelomeningocele and the myelocystocele, the cord is not involved. There are some, as Tournier, who do not look upon a simple meningocele as a constant indication for operation; there are others, again, who adopt a watching and waiting policy and reserve operation for cases where the tumors are rapidly increasing in size and threaten rupture; there are many who exclude as inoperable all forms of spina bifida, except the meningocele. It is our practice to advise operation after the child has passed through the first and crucial year in all cases of simple meningocele. By this process of elimination, the really unfit are sifted out, and the prospects of rendering a service to a child with a reasonable hope of attaining manhood or womanhood are greatly increased.

SPINA BIFIDA OCCULTA differs so essentially from meningocele in certain particulars as to demand special consideration in connection with the indications for operation. As there is in spina bifida occulta no hernia or protrusion, the likelihood of meningitis from ulceration and infection is minimized, although ulceration does occasionally occur. Spina bifida occulta is not at all inconsistent with perfect health and activity, and, as the term implies, may be altogether overlooked. In one of Milner's cases the lesion had not interfered with the patient's assignment to military duty. The defect in this case was at the level of the fourth and fifth

lumbar vertebrae. The indications for operating upon spina bifida occulta are the complications of the lesion rather than the lesion itself. When secondary symptoms (*vide* page 296), caused by pressure upon the cord by a pathological band of tissue, appear, immediate consideration should be given to operation. These secondary phenomena may appear in fetal life, in childhood, or at puberty, although the majority appear between the ages of 10 and 20 years. However, when the signs of pressure once assert themselves, the earlier the operation, the better the prognosis. Should the condition develop in fetal life or should it have existed for any length of time, the degenerative changes in the cord or cauda equina are such that recovery of function is out of the question. There are often associated with spina bifida occulta congenital deformities which have no relation to the spinal defect, and, therefore, no bearing upon this discussion.

Syringomyelocele.—In common with the meningocele, the skin over the syringomyelocele is usually intact. There is, however, always the possibility of ulceration and meningitis to be considered. With syringomyelocele, as with other forms, certain complications must be regarded as contraindications, such as other grave physical anomalies, hydrocephalus or complete paralysis of one or both extremities. It is a little more difficult here to speak so positively of the indications for operation. In general terms, we would urge operation only in selected cases, a middle course, so to speak, as advocated by Muscatello, Bayer, Hildebrand, Henle and others. In the absence of pressure symptoms, or when the evidence of pressure is slight, when there is no ulceration and when rupture is not imminent, we would recommend expectant treatment, because there may be a spontaneous cure, and closure of the defect does not insure against subsequent sequelae. But in the case of large tumors with thinning walls that threaten to rupture, if ulceration be imminent, if there be trophic disturbances and deformation of the extremities with partial paralysis of bladder and rectum, the operation may be undertaken with a certain sense of propriety.

Of all varieties of spina bifida, the meningomyelocele is the least favorable and the most hopeless from every point of view. There seem to be no grounds here for hair-splitting arguments with the *pros* and *cons* of operation, for up to the present time there have been no cases either cured or improved by operation. Of eight cases in von Bergmann's clinic operated upon from the third week to the second year, five died shortly after the operation, two from meningitis, one from hydrocephalus, one from convulsions, and one from pneumonia. Of the remaining three, two died within two months, and one was not heard from; excluding the latter, none were alive two months after operation. The only justification for operation would lie in the fact that without operation death from meningitis is inevitable. The thinness of the medullovascular area and

the direct connection of the central canal with the coverings at the summit of the tumor afford a ready avenue for infection of the cord and membranes. No doubt there may be found isolated instances where some improvement followed operation, as in the case of Lebrun, where the paralysis of the lower extremities was relieved, but these isolated instances are so extremely rare that my own views and those of other authorities may be expressed very positively as not countenancing operative procedure.

Technic.—The treatment of spina bifida resolves itself to-day into a problem of repairing a hernial protrusion in which, in addition to cutaneous, muscular and aponeurotic coverings, the bony defect of the vertebral canal must be considered. The temptation with modern writers is to give little attention to the methods of dealing with spina bifida which were introduced before asepsis; they speak of them apologetically, and pay tribute to their sponsors. I refer to the snaring off of the sac, as recommended by Bell in 1791, and the injection treatment of Morton. While the results in the latter are by no means ideal, the difficulties attending the more formidable operation, the uncertainty of life and the uncertainty of relief from anything but the hernia, compel thoughtful consideration. The relative merits of treatment by puncture, by ligation and by injections were investigated by a committee of the Clinical Society of London appointed to consider chiefly the treatment by the injection of Dr. Morton's iodoglycerin solution. The report is an exceedingly valuable contribution, and the results of the Committee's investigation are instructive:

TABLE IV

	Results				
	Recovered	Unrelieved	Died	Unknown	Total
Treatment by puncture	12	2	30	2	46
Treatment by ligation	10	—	6	—	16
Treatment by excision	16	-	7	—	23
Treatment by injection (iodin solution)	20	1	5	—	26
Treatment by injection (Morton's fluid)	35	5	27	Relieved 4	71

Upon the evidence submitted, the Committee concluded that "notwithstanding many failures, the plan of treatment by injection is the best with which we are acquainted, and the only one which we feel justified in recommending. . . . The best result is to be hoped for in children, who have reached the age of two months, in whom there is no paralysis or hydrocephalus, and when the sac is covered by healthy skin."

The closure of the defect by the open or operative method may be accomplished in various ways. The methods of procedure may be grouped generally into two classes, according to whether operation attempt closure of the bony defect with or without bone. It has been my practice to

vary the technic according to the site and the size of the defect. For example, a small defect in the upper thoracic or cervical region does not require osteoplastic closure, while a large defect in the lower thoracic or lumbar region does. This has served a good working rule, subject, of course, to exceptions. There are those, de Ruyter and others, who contend that the percentage of failures after musculo-aponeurotic closure is so small that osteoplastic closure is unnecessary. This, however, has not been my experience; and, furthermore, I am not in accord with those who believe that recurrence after aponeurotic closure is an evidence merely of increasing intracranial pressure, and the recurrence of a hernial protrusion is an automatic, compensatory means of relief from the ill-effects of increased intracranial pressure. The problem is a very much larger and more complicated one than this, and this explanation of recurrence, while lucid, has not a scientific foundation. Recurrences after operations are the result, on the one hand, of imperfect physiological union at the line of suture, and, on the other hand, of the gradual loss of tone and consequent stretching of the aponeurotic layer, subject, as it is, to constant and continuous pressure.

Briefly, the methods variously recommended include the use of musculofascial flaps (Bayer), the transplantation of a flap from the fascia lata (autoplastic: Brodman), a flap of periosteum with base attached taken from the vertebrae (von Bergmann), osteoplastic closure with a bone flap from the crest of the ilium (Bodroff), from the scapula (Sklifossofsky), filling the defect with fragments of bone from the sacral arches and tuberosities of the sacrum (Zenenko), the employment of a bone transplant taken from the tibia (Albee), closure of the defect by fracturing the bases of the vertebral arches and transferring them to the median line (Dollinger), an adaptation of this principle by Babcock, and the use of foreign materials such as celluloid and silver.

As already indicated, the choice of method should be based upon the size and the situation of the defect. Obviously, the closure of a small opening in the upper level of the canal, involving but a single vertebra, with but little separation of the arch and with the muscles not far apart, requires neither muscle nor bone transplantation. *Per contra,* a large defect, involving two or more vertebrae in the thoracicolumbar region, with a gap of two or more centimeters between the ununited arches and a still wider separation of the muscles, requires for its immediate and permanent closure a more complicated method, and the utilization of tissue which will not yield to continuous pressure. With these fundamental distinctions in mind, it is not a difficult matter to decide at the operation, with structures exposed, which reconstructive method should be used. An analogous situation is found in operations for the abdominal hernias, especially the inguinal, when the choice of method is suggested by the character of the material at hand with which to reconstruct the

canal. No further rules need be laid down in the selection of a method for the operative treatment of spina bifida, and, according to the conditions found, one or the other of the three following methods may be used:

Method 1.—After removal and closure of the sac, an incision is

FIG. 150.—AUTHOR'S SPINA BIFIDA TECHNIC.

1. The dotted line around the neck of the sac represents the point at which the sac is to be amputated.

made in the sheath of the erector spinae muscle around the margins of the hernial orifice, extending 2 cm. or more above and below. If the sheath of the muscle and the muscle itself cannot be approximated without undue tension, vertical incisions are made in the aponeurosis of the muscle near its outer margin, and tension is relieved sufficiently to make approximation in the median line possible without undue tension.

Method 2.—This method I have used to advantage, and will describe it according to my own practice, although in literature the name of Bayer is usually attached to it. It consists in the employment of reflected flaps of the aponeurosis. After the preliminary steps, an incision is made on either side of the defect over the erector spinae muscles, fashion-

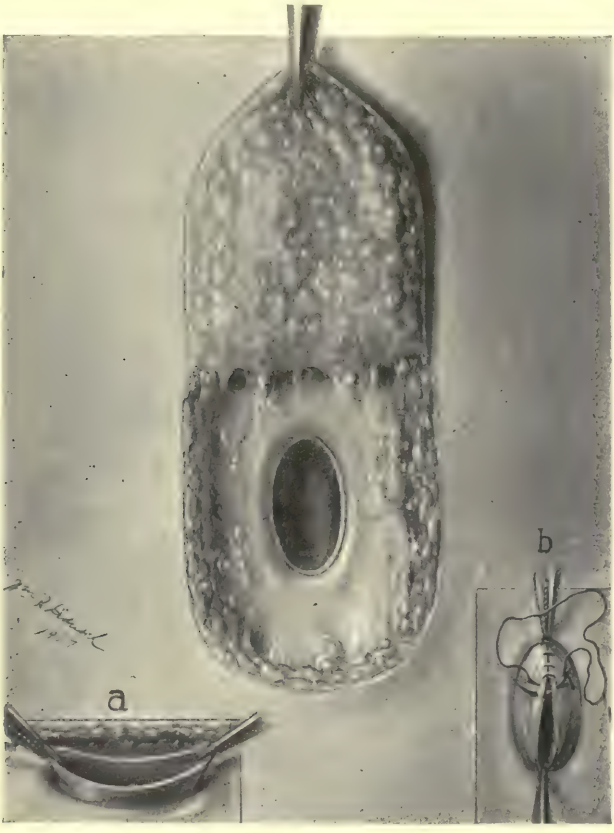

FIG. 151.—AUTHOR'S SPINA BIFIDA TECHNIC (Continued).

2. After the sac has been amputated, the dural margins are closed with continuous silk suture (*a* and *b*).

ing flaps with their bases toward the defect. When possible to do so without jeopardizing the nutrition of the aponeurotic flaps, an incision is made along the margin of the hernial orifice, as in the first method, so that the muscles may be mobilized and utilized to reinforce the aponeurosis. A modification of this method which I have found useful in certain instances, is the construction of U-shaped, instead of lateral, flaps from above and below the opening, after the mobilization of the muscles (Figs. 150 to 157). This modification is to be used only when ample material for lateral flaps is not available, and closure cannot be effected without

undue tension, or without an adequately nourished flap. In every case, no matter what the method, interrupted catgut sutures, single or double strand, have been used.

Method 3.—The first osteoplastic operation was proposed by Dollinger, in 1885, who, after removing the sac, fractured the arches of the fourth and fifth lumbar vertebrae, deflected them toward the median line and sutured them in place. In 1910, Babcock modified or elaborated this

FIG. 152.—AUTHOR'S SPINA BIFIDA TECHNIC (Continued).
3. An incision is made in the aponeurosis surrounding the defect.

technic, as will be seen from the accompanying illustrations. After the preliminary steps, the margins of the bony canal are freely exposed, and with a pair of Satterlee's bone forceps the laminae are divided the entire length of the defect. This is repeated on the opposite side, forming two ribbons of bone and fibrous tissue, each consisting of a chain of imperfect spinous processes and laminae, having attachments above and below. These bony bridges are then united to the median line by sutures of chromicized catgut, thus restoring the bony canal and the position of the rudimentary spinous processes (Fig. 158). A knife is then passed through the erector spinae group of muscles, splitting off on either side a broad strip of

muscle with its overlying aponeurosis. This likewise is left attached above and below and these two musculo-aponeurotic bridges are slid to the median line, reënforcing the bony canal (Fig. 159). In approximating the skin edges, which are usually thin and poorly nourished, it is often wise to evert the edges with mattress sutures so as to bring broader surfaces into apposition. These sutures should not be tied so tightly as to produce strangulation, and may be reënforced by a number of inter-

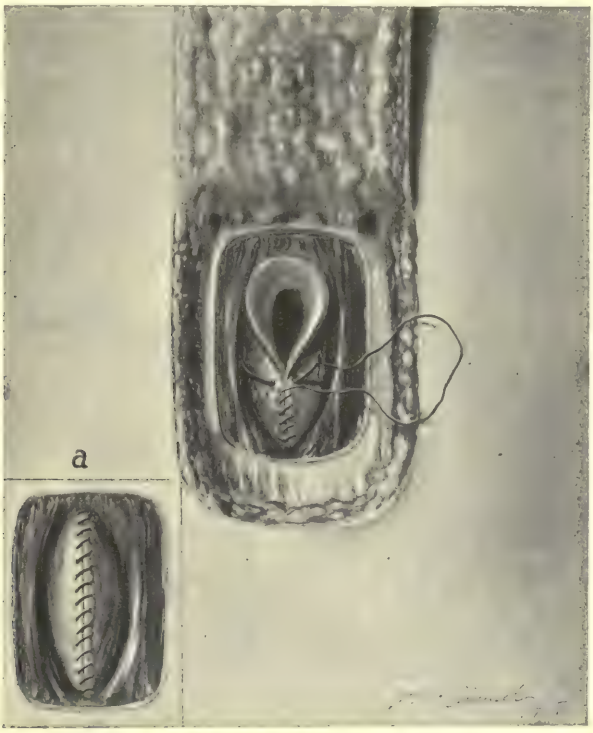

FIG. 153.—AUTHOR'S SPINA BIFIDA TECHNIC (Continued).

4. These aponeurotic flaps are reflected and closed in the median line with a continuous catgut suture (*a*).

rupted sutures of horsehair or other material. In certain cases the skin incision may be closed transversely.

In this operation it is aimed to restore systematically the various structures that should overlie the spinal cord with as little disturbance or manipulation of nerve fibers or cord as possible. The number of layers guard against leakage and infection which present one of the most serious dangers after these operations (Fig. 160). The operation may usually be accomplished in about one-half or three-quarters of an hour, and the shock is surprisingly small. Great care, of course, must be taken to prevent loss of blood, and drainage must not be employed.

Albee's technic is designed for those cases of spina bifida in which, the meningocele having been removed, lordosis develops because of the congenital deficiency in the vertebral arches. The technic, which is somewhat similar to that adopted in Pott's disease, Albee describes as follows: "Modification is necessary on account of the absence of spinous processes and parts of neural arches. The spinous processes above the cleft and the lateral masses of the last lumbar vertebra and the first part of the

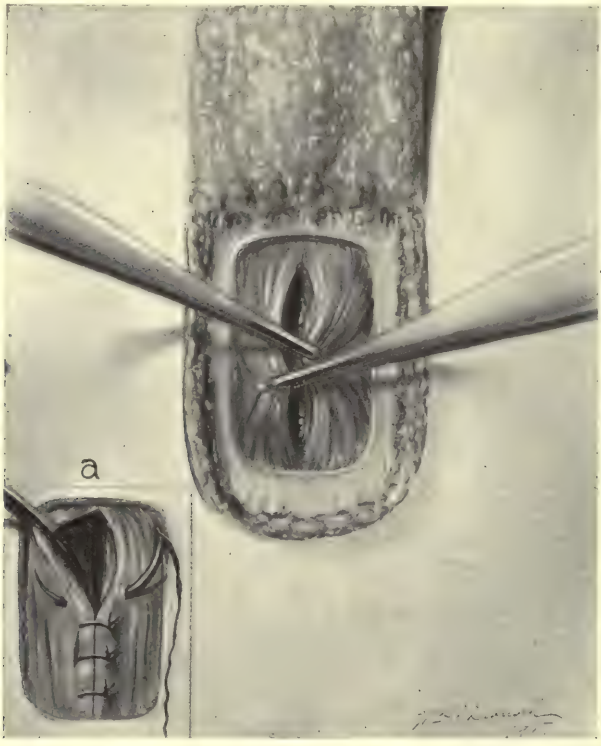

FIG. 154.—AUTHOR'S SPINA BIFIDA TECHNIC (Continued).

5. The third layer in the closure of the defect is repaired by the mobilization of the muscles on either side of the defect, which are secured in the median line with interrupted catgut sutures (*a*).

sacrum are reached from each side by two curved skin incisions, as it is undesirable to interfere with the nerve tissue which is usually involved in the cicatrix following the operative reduction of the meningocele. The second spinous process above the cleft is split longitudinally and a green stick fracture produced in each half. The first spinous process above the cleft is denuded of its muscular and ligamentous attachments and both sides freshened. Below the cleft the lateral masses of the fifth lumbar vertebra, or the congenitally deformed stumps of the neural arches if sufficiently prominent, and the first segment of the sacrum, which is usu-

ally congenitally hypertrophied, are split with the osteotome, and the halves separated to receive the lower ends of the two grafts.

"The wounds are packed with a saline compress and the two grafts are prepared and removed from the crest of the tibia, long enough to reach from the split spines above to the sacrum below (Fig. 161). The upper ends are beveled, so that when these beveled surfaces come together the

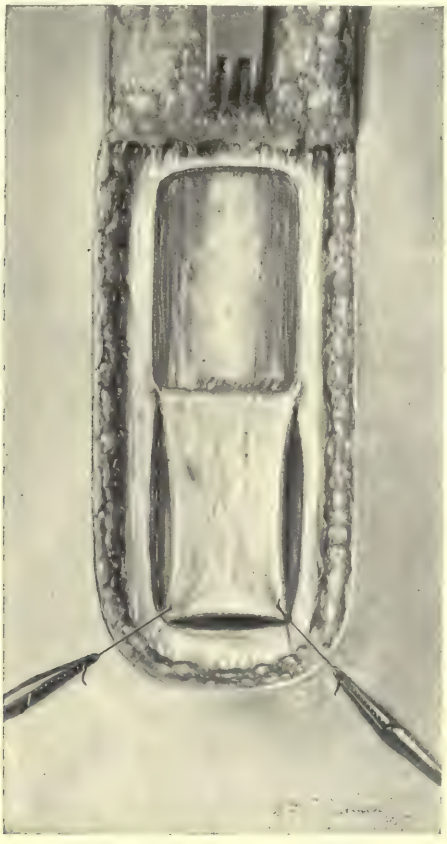

FIG. 155.—AUTHOR'S SPINA BIFIDA TECHNIC (Continued).

6. The muscle layer is reënforced by the reflection of a U-shaped aponeurotic flap from above, secured in place with interrupted sutures.

grafts form an acute angle, like an inverted V. The grafts are placed at this angle in the beds prepared for them, and held firmly in place at their bony contacts by drawing the split ligaments over them with interrupted sutures of medium kangaroo tendon. The technic is similar to that of the bone-graft applied for Pott's disease. Skin wounds are closed, and the patient placed on a fracture bed for six weeks."

Upon the variety of the lesion (meningocele, myelocystocele, menin-

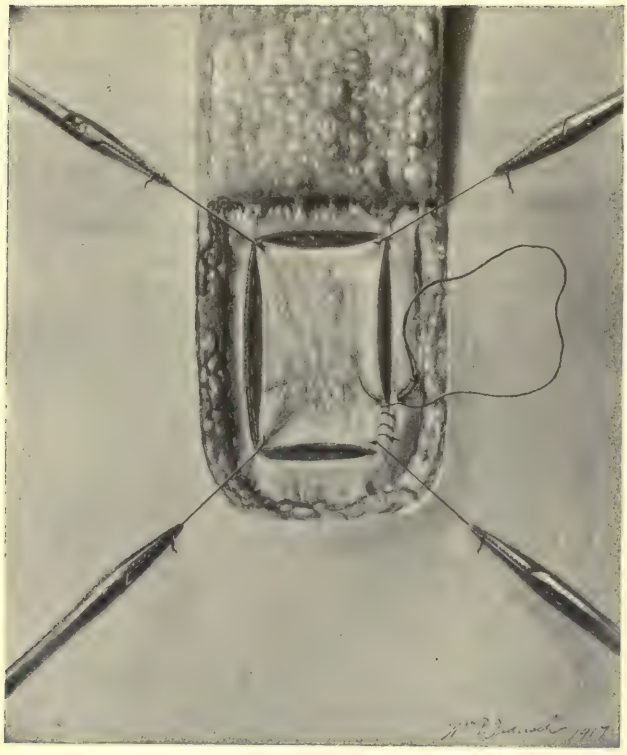

FIG. 156.—AUTHOR'S SPINA BIFIDA TECHNIC (Continued).
6*a*. Another way of reënforcing the muscle layer, by a transplant from the fascia lata.

FIG. 157.—AUTHOR'S SPINA BIFIDA TECHNIC (Continued).
7. The final appearance of the wound after the reflection of the U-shaped cùtaneous flap.

gomyelocele) will depend somewhat the manner of dealing with the sac and its contents.

Isolation of the Sac.—In all varieties the sac must be isolated first, sharp dissection without rude handling of the structures being imperative. In this dissection it is not always easy to avoid puncturing the

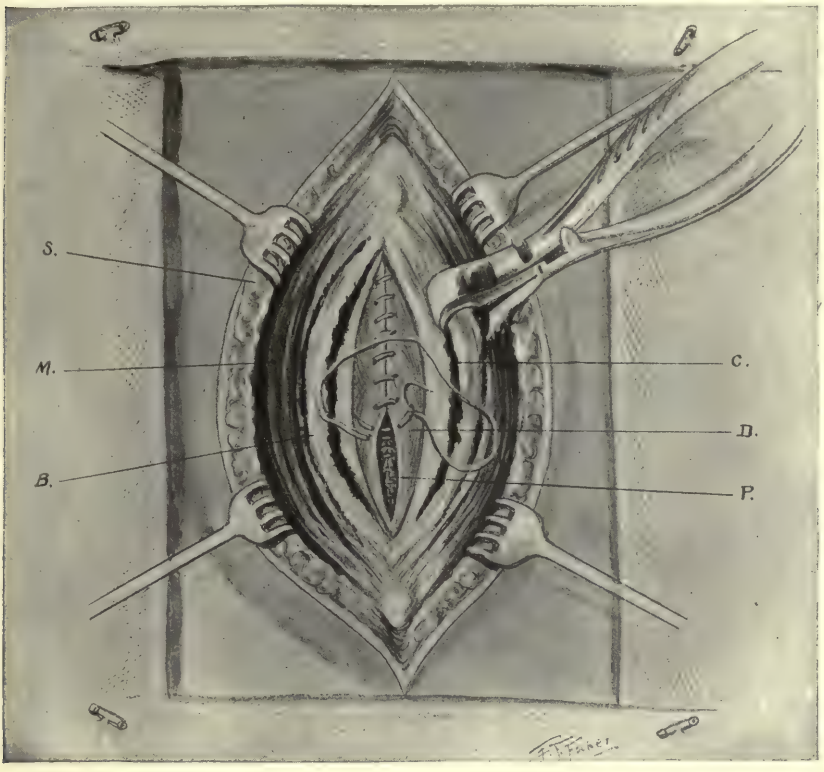

FIG. 158.—BABCOCK'S OPERATION FOR SPINA BIFIDA.

The closure of the separated dura is shown, as is also the mobilization by Satterlee forceps of fibro-osseous ribbons consisting of the rudimentary lamina. P., sutured pia-arachnoid; D., dura in process of closure; B., C., mobilized fibro-osseous ribbons which are to be brought to the median line and sutured; M., erector spinae muscle; S., skin.

sac, as it is often extremely thin, especially as one approaches the neck or margin of the defect. At this point the dura blends with the inner surface of the laminae, and an incision must be made on either side of the defect in order to free the dura from its margins and throughout its entire circumference, so that when the sac is tied off or closed with sutures, the stump will lie within the spinal canal.

Opening of the Sac.—Before the sac is opened, an attempt may be made by transillumination to determine the presence and position of

the spinal cord and roots, and the initial incision should be so made as to avoid the nervous contents.

Management of Contents.—(*a*) *Meningocele.*—The sac is opened in the median line, its contents explored, and if entirely free from roots, the redundant portion excised and closure effected with a continuous silk

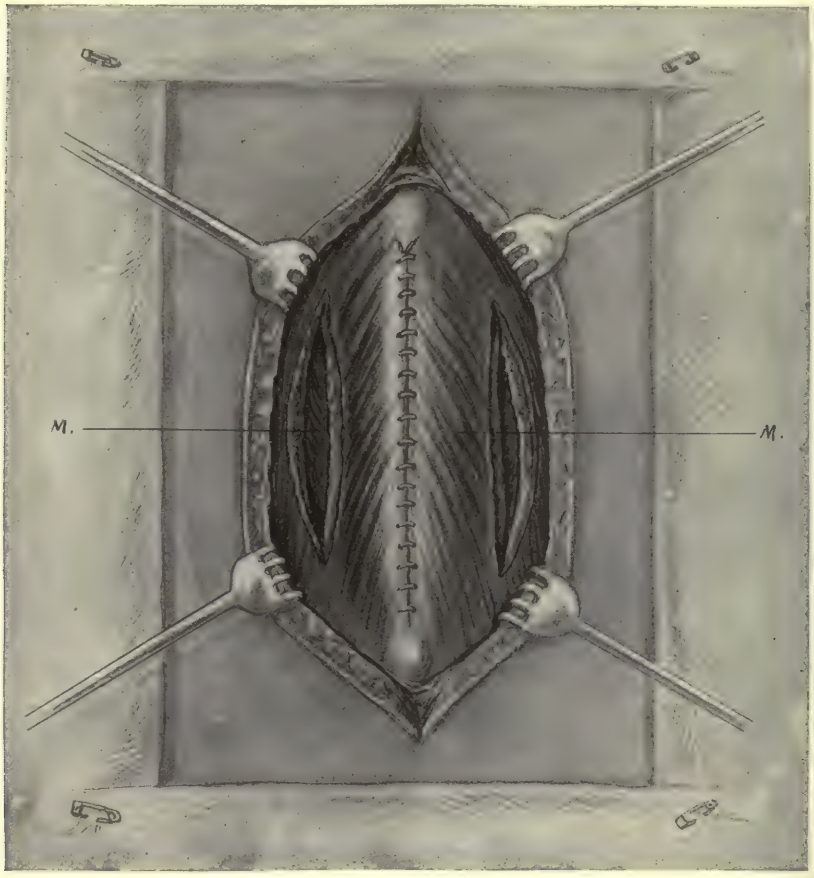

FIG. 159.—BABCOCK'S OPERATION FOR SPINA BIFIDA (Continued).
The membranous and bony canal having been formed, musculo-aponeurotic flaps fashioned from the outer layers of the erector spinae are slid to the median line and sutured.

suture. When the meningocele is situated in the upper (cervicothoracic) levels, the sac rarely contains nerve roots, and even at the lumbosacral level the roots are not always in the sac. If present and unattached, the roots should be returned to the canal, and the sac resected so as to provide flaps of sufficient dimensions to prevent pressure on the contents of the canal. On the other hand, if the roots be adherent to the sac, they may

be either separated at their point of attachment or divided at their entrance to the sac and removed with it. When in exceptional cases these roots are distributed as a fine network over the interior of the sac, isolation is impossible and the network must be removed with the sac.

(*b*) *Myelocystocele.*—The difficulties attending operations are apparent. Chief among them are the dissection of the skin from the sac (pia) and the disposition of cord and cyst. When the cyst is small it may be replaced intact, or tapped and replaced. However, if the cyst be of larger dimensions, simple evacuation is insufficient. Under these cir-

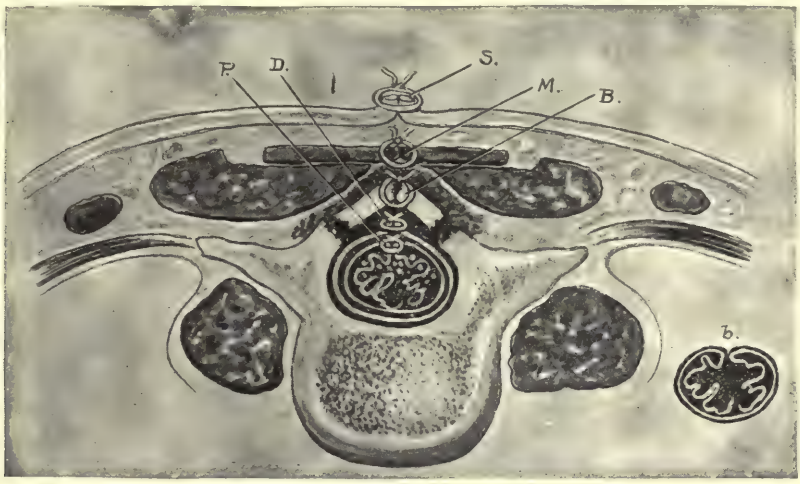

FIG. 160.—BABCOCK'S OPERATION FOR SPINA BIFIDA (Continued).

Cross section (diagrammatic), showing method of operative reconstruction of spinal canal. P., pia-arachnoid; D., dura; B., mobilized lamina; M., musculo-aponeurotic flaps; S., skin; *b.*, illustrates method of infolding pia with attached cord or nerve-roots.

cumstances enough of the sac must be resected to enable the cord to be replaced, and this is especially indicated when the posterior part of the cord is thin. In Hildebrand's and von Bergmann's clinic, this operation has been carried out sufficiently often to demonstrate its advantages. In all cases the separation of the pia from the skin is difficult, as the two layers are so closely adherent.

(*c*) *Myelomeningocele.*—Of the three varieties this is the most hopeless, and any discussion of the relative merits of operative intervention assumes a more or less academic nature. Whatever the procedure adopted, one principle must be observed in all, namely, the preservation of the area medullovasculosa, which contains the ganglion cells. To avoid injuring the nerve-roots, the sac is opened by a transverse incision and its contents explored. If the nerve-roots be free, a portion of the redundant sac may be removed and the roots returned to the canal with the area medullo-

vasculosa. When the roots are adherent to the sac wall, the sac *in toto* is replaced without further interference.

(*d*) *Spina-Bifida Occulta.*—The indications for operation are here more sharply defined. The operation is usually postponed until the symptoms of pressure from the membrana reuniens manifest themselves. In the case reported by Jones the spinal deficiency corresponded with the spine of the second sacral vertebra, and a sufficient portion of the first sacral vertebra was removed to expose the cauda equina, which was found compressed by a dense adventitious fibrous band stretched across the spinal canal. This was about 1¼ cm. wide, its upper border quite free, and

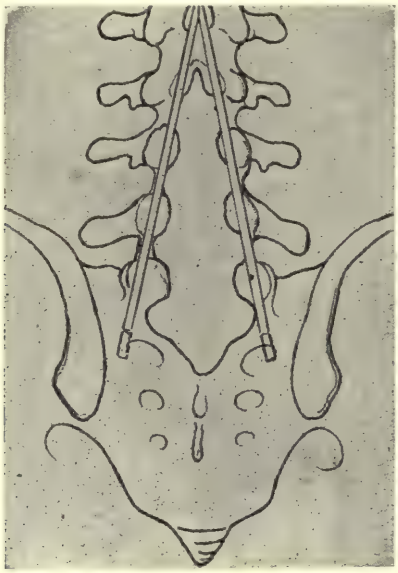

FIG. 161.—DIAGRAM SHOWING ALBEE'S METHOD OF STRAIGHTENING OR SUPPORTING BIFID SPINE BY THE INSERTION OF AUTOGENOUS TIBIAL GRAFTS.

its lower border in contact with the cicatricial tissue of the spina bifida. The band was divided in the middle over a director and the two halves removed. The cauda equina thus exposed was deeply grooved by the band, and the pressure symptoms thus readily accounted for. Six months later the patient was free from pain and had regained sufficient power to walk. Once the band is removed the operation is practically completed.

Prognosis.—A forecast of the future after operations for the various forms of spina bifida must consider the immediate result of mortality, the effect of the operation upon existing paralysis, and the development of complications, such as hydrocephalus. The immediate mortality after the radical operation, though varying according to the type, has been estimated

in round numbers at from 25 to 35 per cent, although, if the mortality included the fatalities of the first year after operation, the percentage would rise to 50 per cent or higher. In the 44 cases in Hildebrand's clinic, 20 were subjected to the radical operation, and of these, 9 or 47.4 per cent died, 8 or 42.1 per cent were discharged as recovered and 2 or 10.5 per cent as improved. The causes of death in this, as in other series, were chiefly meningitis and hydrocephalus. By way of contrast, the fate of the unoperated cases may be given: there were 20 cases with 17 deaths (77.3 per cent) and 3 discharged as unimproved (22.7 per cent). In Moore's collection of 385 cases operated upon since 1885, the immediate mortality was 24 per cent, but there should be added to this 7 per cent of the survivors who died within three months. Roswell Park reported fourteen cases operated upon in his own clinic with two deaths (14.2 per cent). Lovett collected a series of 88 cases from various sources with 30 deaths (mortality 34 per cent).[1]

Generally speaking, the prospect of recovery will be greater in the meningomyelocele or cystocele, when the overlying skin is not ulcerated, and when the child is otherwise well developed and physically sound. The prevention of meningitis is a matter of refinement of technic, applicable to all operations upon the central nervous system. As to the second most common cause of death, hydrocephalus, ignorance of the cause denies us the adoption of prophylactic measures. Hydrocephalus may or may not be caused by, and therefore be a complication of, spina bifida. That it does develop after operation is well known, but that it develops in cases that have not been operated upon, or those in which the operation has failed in its purpose, is equally true. It is useless, therefore, to speculate as to the cause of postoperative hydrocephalus, and attribute it, as some do, to a diffuse aseptic meningitis, but from the philosophical standpoint it is well to recognize that spina bifida, like syringomyelia and many cases of hydrocephalus, postulates not only a perverted evolution in the embryological stage, but also a lack of sufficient tissue *vis a tergo* whereby growth and function are normally maintained, and without which regression and degeneration may be looked for early in life. Therefore, let us be careful not to see too certainly cause and effect in spina bifida and hydrocephalus after operation, but rather let us admit the possibility of hydrocephalus being an exhibition of primary weakness in the patient's growth. The following is a record of a patient from my own clinic, in whom hydrocephalus developed after an operation only partially successful.

Spina bifida of the thoracicolumbar region. Operation at the age of six months showed that the terminal portion of the cord was involved in

[1] Bayer, Prague Clinic, 17 cases, 9 died; Bockenheimer, Berlin Clinic, 20 cases, 7 died; Sachtleben, Breslau Clinic, 18 cases, 6 died; Mayo-Robson, 20 cases, 5 died; Hildebrand, 13 cases, 3 died.

the sac contents; a portion of the sac was excised and the remainder replaced in the canal, but hydrocephalus gradually developed and there was a recurrence of the cystic protrusion at the site of operation.

The patient, *aet.* six months, was the younger of two children, the older being normal and healthy. The child was born with a spina bifida of the thoracicolumbar region, involving the thoracic and the lumbar vertebrae. There was complete paraplegia and partial paralysis of the bladder and rectum.

Operation, December 9, 1911. Under ether anesthesia, with the patient in the Trendelenburg and prone position, a curved incision was made, a flap reflected, the sac exposed and opened. The sac contained a network of roots and the terminal portion of the cord. The separation of these from the sac was impossible; therefore, a portion of the redundant sac was excised, and the remainder infolded and replaced within the vertebral canal. The arches of the vertebrae on either side were fractured after the Dollinger method and inclined toward one another, but the defect was so wide that they could not be brought into apposition. The defect was reinforced with muscles and aponeurosis from either side and the cutaneous flap replaced.

The wound healed by first intention, and the child's convalescence was uncomplicated until, three months later, a gradual though asymmetrical and disproportionate increase in the size of the head was noticed. About the same time a hernial protrusion at the site of the operation was observed. Three years after the operation there was a moderate hydrocephalus, and at the site of the operation a defect of 6 cm. long and 3 cm. wide with an oval swelling. There was a slight equinovarus of both feet; paraplegia was still complete, but expulsive power of the bladder had been fully restored. The simultaneous development of a hydrocephalus and a return of the meningocele are the significant features (Fig. 162).

It is difficult to estimate in figures the end results of operative interference, as but relatively few cases are put on record at any considerable period after the operation, but here and there we find reports of isolated cases which have passed the convalescent period, such as Kirmisson's two cases of myelocystocele practically well two years after operation. One of Perier's patients was reported well 21 years after the operation and had given birth to a normal child. In my own clinic the longest survival was that of a meningocele in the lumbar region.

Spina bifida in the lumbar region. Operation at the age of fourteen months; the cord which was found attached to the sac was freed and returned to the canal. Nine years after the operation, the child showed no mental or physical defects with the exception of a bilateral talipes varus and slight nervous movements of the head at times.

The patient, a little girl *aet.* 14 months, was admitted to my service at the University Hospital, October 10, 1906 (File No. 1353). She was the child of healthy parents, and had one brother four years of age who was normal and in good health. At birth a swelling the size of a hen's egg was noticed in the lumbar region; the overlying skin was healthy from the first and remained so.

Operation, October 10, 1906. Through a transverse incision the sac was exposed and opened. The terminal portion of the cord was contained in and adher-

ent to the sac. The point of attachment was freed, the cord returned to the canal, and the defect closed with flaps from the sheaths of the erector spinae muscles.

Convalescence was uninterrupted. The child was examined February, 1915, nine years after the operation; there was no recurrence at the site of operation, no mental or physical defects, except a bilateral talipes varus, which was observed

FIG. 162.—SPINA BIFIDA PATIENT OPERATED FIVE YEARS BEFORE.

Three months after operation there were signs of recurrence and evidence of beginning hydrocephalus.

as soon as the child began to walk and had continued ever since. The child had a nervous temperament and at times there were movements of the head and neck similar to those of a spasmodic torticollis.

In one of Cates's cases, in spite of the fact that the patient was a man 34 years of age at the time of operation, there was complete recovery and no untoward symptoms had developed six years after the operation. The

meningocele had always given him some trouble, causing shooting pains down the limbs, weakness of the lower extremities, constant pains in the

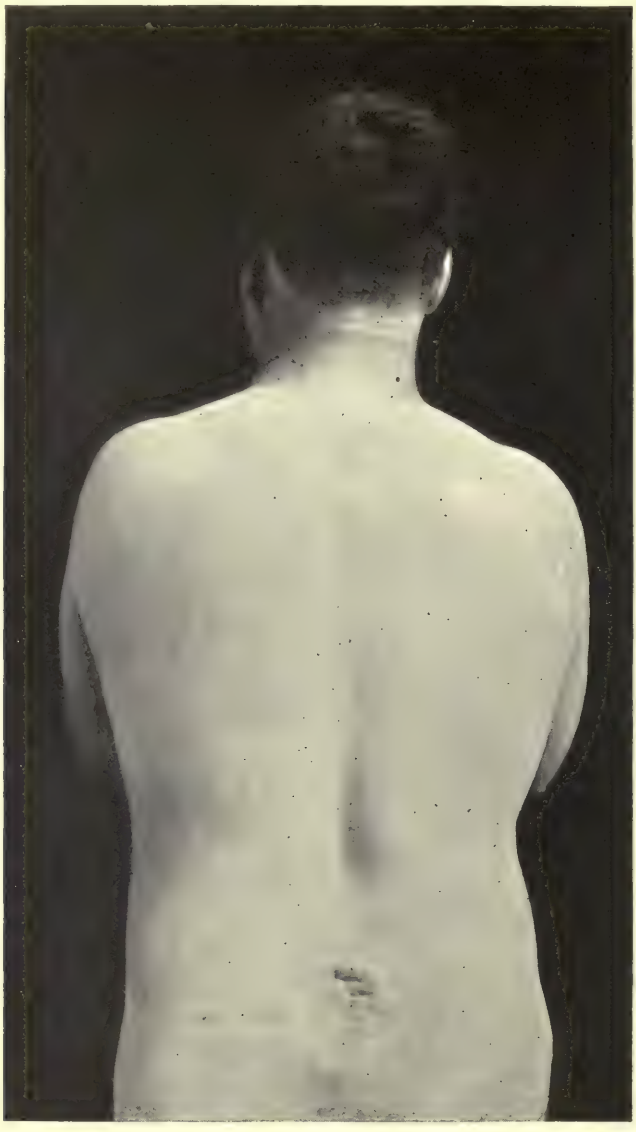

FIG. 163.—SPINA BIFIDA PATIENT SIX YEARS AFTER RADICAL OPERATION FOR MENINGOCELE. (Cates.)

penis, and at times lack of control of the rectum. In a personal communication from Dr. Cates I am told that he is now a "husky chauffeur in the best of health" (Fig. 163).

In exceptional cases, after an interval of freedom from complications, where the defect has been repaired and there has been no recurrence, hydrocephalus, idiocy, motor and trophic disturbances may appear. The development of functional lesions at varying periods after the operation may be due to adhesion of the cord, roots, or membranes to the margin of the defect, or to the fact that as the patient grows there is no correlation between the lengthening of the cord and the lengthening of the vertebral canal. Thus traction upon the cord or roots might readily lead to sensory, motor, or trophic disturbances.

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CHAPTER VI

TRAUMA

SPRAINS OF THE SPINE

Sprains or distortions of the spine, in the character and nature of the injury, are analogous to sprains of other joints. There is, however, the important distinction that sprains of the vertebral column may involve more or less serious damage to the spinal cord. Because of the greater mobility of the cervical segment of the spine, this is the more usual seat of sprains and next in order of frequency are those in the lumbar region, especially at its junction with the thoracic vertebrae. The injury may be produced either by a blow, transmitted in the direction of the longitudinal axis of the vertebra, or by a fall upon the head or back. Sometimes sprains may result from an effort to lift heavy weights. As a matter of fact, the mechanism of sprain differs little from that of fracture or dislocation. The injury implies either overstretching or minute or extensive laceration of the ligaments or capsules, and, according to the extent of ligamentous injury, there may be more or less transitory disarrangement of the normal relation of one vertebral body to the other. When the bodies do not return to their original relationship the lesion is converted into a true dislocation. The injury to the cord that one often sees in traumatic lesions of the cervical spine, where the x-ray reveals neither dislocation nor fracture, can be explained only on the assumption that through the pathological increase in the range of motion the cord is subjected to a process of overstretching or direct pressure. The resulting lesion may be one of contusion, laceration or hematomyelia of the cord, extradural or intradural hemorrhage.

The clinical manifestations of sprains include voluntary restriction of motion, pain on active or passive motion, tenderness on pressure over the spinous processes of the injured vertebra, the absence of evidence of fracture or dislocation and in a certain percentage of cases, relatively more frequent in the cervical region, the symptoms of a cord lesion. The clinical picture must vary according to whether the injury is mild or severe. In the milder forms of sprain, disability and pain may be so trivial as to make the diagnosis of sprain almost questionable, while more serious forms are readily recognized not only by the symptoms referable to the damage of the ligaments, capsule and intervertebral disks, but by the evidence of a cord lesion. There may be some slight increase in the activity of the tendon

reflexes, but this is in the nature of a reënforcement and not due to the lesion of the cord, and may be detected above as well as below the level of the injury.

The diagnosis of sprain should not be accepted without an examination of the injured level of the spine by an experienced roentgenologist, whereby alone the existence of fracture or dislocation may be determined. The pain, the attitude of the head in sprains of the cervical region, the absence of any disalignment of the spinous processes characteristic of dislocation or fracture-dislocation and negative x-ray findings are points to be considered in the differential diagnosis. A forecast of the eventual result of sprains should be given with great caution.

In all cases a guarded prognosis should be given, since what may at first appear a trivial injury may be the inciting factor of serious sequelae, such as tuberculous spondylitis, other forms of arthritis, syringomyelia, or hematomyelia. Furthermore, sprains of the spine are not infrequently the basis for damage suits, which of themselves have a deterring effect upon the patient's recovery.

Sprains of the spinal column seem to require consideration separate from sprains in other parts of the skeleton. This is due in a measure to the fact that often such injuries are caused by acts of great violence and partly because of the associated injury to the spinal cord and its distributive roots. At all events, in the mind of the patient, a sprain of the spine signifies an injury of greater potentiality than that of other joints, and frequently, as in "railway spine," such sprains are the basis for the introduction of a prolonged state of invalidism. It is important, of course, to eliminate an associated fracture, difficult as this sometimes may be, although when the processes alone are involved, the treatment needs little, if any, modification. Since the introduction of roentgenology, it is possible with greater certainty to differentiate a sprain from a fracture, or *vice versa,* and in the light of our x-ray experience many cases hitherto looked upon as sprains were unquestionably fractures.

Essentially the treatment should consist of physiological rest enforced, at first, in bed. In sprains of the cervical region immobilization may be attempted with sand bags on either side of the head, supporting the neck with a roll cushion, and with extension applied to the head and counter-extension by elevation of the head of the bed. Within several days, or in some cases several weeks, the pain and tenderness will have subsided, and the patient may get up with some form of support, be it a brace, a leather jacket or light plaster cast. Such rigorous measures may not be required in all instances, as the severity of the sprain may vary from one of a trifling to one of grave nature with associated cord injury. In the milder cases enforced rest in bed may be dispensed with and relief afforded by a dressing of adhesive plaster. When the tenderness persists there is much to be gained by properly directed massage and occasionally by coun-

terirritation. Premature resort to active or passive motion should be cautioned against, especially in the presence of persistent tenderness.

CONTUSION OF THE VERTEBRAE

Contusion of the vertebral bodies or the ligaments is a condition more often implied or suspected than actually demonstrated. When the spine has been subjected to direct or indirect injury, the result of a fall or blow upon the head or buttocks, and the findings are neither those of sprain nor compression-fracture, it might be proper to regard the injury as of the nature of a contusion. The mechanism of contusion is not unlike that of compression-fracture in that the usual cause is a fall upon head or buttocks—usually the latter—and in contradistinction to sprain, the site of predilection is in the lumbar vertebrae. In this region of the spine the vertebrae, through the superimposed weight of the trunk, are subjected to the greatest pressure and violence. Next in order of frequency is the thoracic and, finally, the cervical region.

In differentiating *contusion* from *sprain,* there are four essential points of distinction: contusion is most common in the lumbar, sprain in the cervical region; contusion is accompanied sometimes by great bruising of the soft parts, skin, subcutaneous tissue and musculature; contusion is accompanied only exceptionally by cord symptoms, sprain not uncommonly; and contusion may be attended with structural changes in the vertebrae and ligaments—as elicited by the roentgenogram—that are not a part of the pathological findings in sprain. To establish a sharp line of distinction between contusion with vertebral deformity and compression-fracture would indeed be difficult and of only academic interest. Not infrequently have cases of contusion of the spine passed unrecognized and been improperly treated as lumbago or as a mere contusion of the soft parts.

A contusion of the spine, when due to more than a trivial injury, will provoke pain on motion with voluntary immobilization of the injured segment and pain on firm pressure over the spinous process of the injured vertebra. In but exceptional instances will there be any evidence of cord lesion. A roentgenogram in which the content and outline of the vertebral bodies are clearly depicted may reveal immediately after the injury some irregularity of the upper and lower margins of the body, chiefly on the anterior aspect, and at a later stage evidence of callous formation in the form of projecting spicules of bone. The slightest evidence of compression of the body, of displacement of any fragment from the articular margin or elsewhere, or of evidence of structural changes other than those above described, must be interpreted as the signs of compression-fracture rather than contusion. The treatment of contusion must be carried out along the same principles as prescribed for sprain. Fixation should be enforced until pain

and tenderness have subsided, at least, to a pronounced degree. The employment of a brace is indicated when, in ambulant cases, movements are still accompanied by much discomfort; massage is of great value in encouraging the absorption of the traumatic exudate.

CONTUSION OF THE INTERVERTEBRAL DISKS

While contusion of the intervertebral disks usually occurs as a complication of total dislocation and fracture-dislocation, particularly in the lower thoracic and upper lumbar region, it occasionally occurs independently. It is more likely, however, that the large number of cases which have been reported as isolated contusions of the intervertebral disks have in reality been but the accompaniments of much graver lesions. When contusion of the vertebral disk occurs as an isolated lesion, it is accompanied by disturbance of motion, more or less marked according to the degree of the contusion, by pains which may be only local or may be radiating, tenderness to pressure, pain on motion and prominence of the spinous process of the vertebra next above the injured one. Pressure on the head and shoulders also causes pain, as in sprains.

DISLOCATION OF THE VERTEBRAE

Compared with fractures or fracture-dislocations of the spinal column, pure dislocations are relatively infrequent. It has been grossly estimated that in every hundred cases of injury of the spinal column, 60 will be fracture-dislocation, 20 isolated fractures and 20 isolated or pure dislocations. It is of little moment, however, what the actual percentage may be. Nor do I propose to continue the time-honored discussion as to whether there is such a lesion as a pure dislocation, and as to whether in the terminology it would be proper to style an injury a dislocation where there is associated a fracture of an adjacent process which in respect to the etiology, prognosis, or treatment might be quite non-essential. There seems to me no doubt that there are unquestionably a certain number of cases in which the lesion is a dislocation pure and simple without demonstrable fracture either of the vertebral body or of the several adjacent processes. In our consideration, therefore, of the subject of dislocations in general, and of individual dislocations in particular, we have confined our discussion and illustrations to those cases in which the evidence seemed to point quite clearly to a pure dislocation.

In contradistinction to a sprain, dislocation of the vertebra implies an injury in which there has been complete separation of the articular processes on one (unilateral) or on both (bilateral) sides and I have followed

the common usage in speaking of the upper rather than the lower as the dislocated vertebra. To those injuries in which the intervertebral disks have been torn and the vertebrae separated from each other in their vertical axes, but without disturbance of the plane of the articular surfaces to each other, is applied the term *diastasis.*

To understand the mechanism of dislocations of the vertebrae an attempt must be made to visualize as far as possible the rather complicated movements of the spinal column in various directions. Normal range of motion, though slight between individual processes, is reasonably wide when the entire spinal column is taken into consideration. Furthermore, the range of motion is limited by the compressibility and elasticity of the intervertebral disks and by the ligamentous and capsular attachments about the articulations. There are to be considered two axes through which the spinal column may move: one in the direction of flexion or extension, that is, through a horizontal plane; the other is a movement of lateral inclination around an anteroposterior axis, the center of which is in the median plane. Through one axis the movements are of lateral inclination and rotation, and through the other, flexion and extension.

Pathology.—The occurrence of dislocation implies an injury to the vertebral disk, capsular or other ligaments, blood vessels and roots, muscles and in some cases the spinal cord and its membranes. In every instance there will be more or less extensive laceration of the capsular ligament on one or both sides, according to whether the dislocation is unilateral or bilateral. Of the other ligaments those between the spinous processes and laminae and those between the transverse processes may be torn and the anterior and posterior ligaments may be severed from their bony attachments. Complete severance of the attachments of the anterior ligament is extremely rare, so that the displacement of the vertebral bodies from one another is thus guarded against. The blood vessels, more particularly the large venous plexuses, both within and without the spinal canal, may suffer to a greater or less extent and there will always be more or less hemorrhage. Fortunately the vertebral arteries, although so fixed in their course, usually escape injury. When hemorrhage occurs, it may be either within the vertebral canal, without or within the spinal membranes, or may surround the vertebral bodies and infiltrate the tissues on the anterior aspect, as in the cervical region beneath the tissues of the pharynx. Dislocation of a vertebra implies usually injury to the intervertebral disk which is torn, either in whole or in part, from the adjacent vertebrae.

Sometimes the intervertebral disk may be separated partly from the superior and partly from the inferior vertebral body, and in some cases again it may be crushed, or may be displaced backwards and encroach upon the contents of the vertebral canal. The displacement of one articular process from another exposes to injury the nerve-roots as they emerge from

the intervertebral foramina. Thus the roots may be contused, compressed, or lacerated. In the cauda equina more particularly are injuries to the roots observed when, after displacement, they are caught between the body of the vertebra and the laminae.

In my collection of 44 cases of dislocation of the cervical region, the cord was involved in 31, in 9 of which there was complete transverse lesion and in 22 an incomplete lesion. In 5 cases of dislocation of the lumbar region there was no involvement of the cord in 2 and in 3 an incomplete lesion; thus in 49 cases the cord was damaged to a greater or less extent in approximately 70 per cent. Injury to the cord may be due to overstretching or elongation, to direct bony pressure, or to the effects of hemorrhage within or without the dura. Because of the wide range of motion in the cervical region and of the greater incidence of dislocations in this region of the spine, cord injuries are here more frequently met. The greatest danger, according to our statistics, seems to be at the level of the fifth and sixth cervical vertebrae. The frequency of cord involvement, according to Blasius, varies with the different varieties of dislocation. In the bilateral dislocations, either backward or forward, of the thoracic or cervical vertebrae, the cord is most frequently involved; next in order of frequency in the unilateral dislocation forward, and finally, in the bilateral dislocation in opposite directions.

Symptomatology.—The symptoms of dislocation are those ascribed to the injury to the structures entering in the formation of the joint and those ascribed to injury to the cord and its membranes. Among the former may be included localized pain and tenderness, limitation of motion due in part to the muscular rigidity and in part to the dislocation itself and the deformity. The latter may be recognized by the peculiar attitude of the head and neck, by the disturbance of the alignment of the spinous processes or, as in unilateral dislocation, by the prominence of one or the other of the transverse processes. In dislocations in the cervical region the displacement of a vertebral body may be detected upon inspection or palpation of the pharynx. Symptoms which arise from an injury to the spinal cord itself or to the roots differ in no special particular from those which accompany fracture or fracture-dislocation. There may be a hematomyelia, disturbance of function from pressure of a blood clot, as in hematorachis, or evidence of more or less complete cord injury, whether the lesion be one of compression, contusion, or laceration. Perhaps more frequently in dislocation than in fracture will the symptoms be due to compression, whereby the structure of the cord has not been injured beyond the point from which recovery may be possible when the compression is relieved by reduction. This is particularly true of unilateral dislocation forward of the cervical vertebra.

Generally speaking, the differential diagnosis between fractures and dislocations will depend upon the presence or absence of crepitus, preternat-

ural mobility and upon the roentgenogram. In injuries of the cervical region where the displacement of the several processes is more easily detected by palpation, the dislocation may be recognized by the disturbed relation of the transverse or of the spinous processes. The peculiar attitude of the head in dislocations of the cervical region is an important diagnostic sign. In many points, however, the symptoms of dislocation and fracture are alike; as for example, in the character of the injury, in the presence of pain, of muscular rigidity, of fixation and of the accompanying injury to the spinal cord.

Dislocation of Occiput from Atlas.—The articulation between the atlas and occiput is one which permits of flexion and extension only and is composed chiefly of the condyles of the occipital bone on the one hand and the oval concave surfaces of the atlas on the other. This articulation is fortified by strong ligamentous attachments between the two bones as well as by ligaments within the canal, which together make separation of one bone from the other so difficult that the effect of forceful movements in this region is usually transmitted to lower segments of the cervical vertebrae. Hence, luxation of the atlas from the occiput is extremely rare, but all doubt as to its occasional occurrence has been dispelled by the records of a few cases. In one of these, the case of Coste, the patient, a boy fifteen years of age, was thrown down and given a number of violent blows on the back of his neck. As a result, the odontoid process of the axis was broken and the atlas was displaced forward from its articulations with both the occipital bone and the axis. His head was immediately bent forward, movements of the neck became restricted, hyperesthesia and paralysis of motion lasted for four months, at the end of which time pain appeared in the right upper and lower extremity. The posterior part of the axis projected slightly on the right; the chin, which almost touched the chest, was turned sharply to the left. The patient died thirty-six days after his admittance to the hospital; autopsy showed a backward dislocation of the occiput from the atlas, which was tilted forward upon the axis and rotated to the left anteriorly and to the right posteriorly. The odontoid process, which had been broken off at the base, was reunited with the body of the axis by fibrous tissue. In the case of Milner, the patient was instantly killed upon falling a distance of seventy feet. There was complete dislocation of the occipital bone from the atlas and axis, all ligaments on both sides being completely severed. Similar cases have been reported by Bonisson and by Hartmann (quoted by Wagner and Stolper) in which the patient died immediately, and Malgaigne has collected three cases in which there has been an incomplete dislocation. There is no prescribed formula for reduction. Traction should be made upon the head, and according to the direction of the displacement counterpressure must be made upon the vertebra.

Dislocation of Atlas from Axis.—In the description of this articu-

lation, attention is called to the fact that there are two articular processes, the two lateral articulations and the articulation between the arch of the atlas and the odontoid process of the axis. The articulating surfaces are directed downward and outward and slightly forward, and upon them the atlas glides upon the axis. According to Corner, the ligaments of these joints are lax and loose, so that the fixed position of the head is maintained by muscular effort, without which the head may rotate thirty degrees on either side of the median line. Dislocations of the atlas from the axis are not so infrequent as commonly supposed, one observer collecting twenty cases of one variety alone, and many have occurred undetected. In many instances, there is an associated fracture of the odontoid process. The dislocation is usually the result of direct violence, although there are instances in which the injury can be accounted for only by muscular action. A blow upon the forehead, as in falling from a distance or downstairs, when the force is directed from above downward, is the usual mechanism.

Several varieties have been described: dislocations forward, dislocations backward, and rotary displacements, bilateral and unilateral. In *dislocations forward,* there is a more or less marked degree of displacement, varying from a slight inclination of the atlas on the axis to a gliding of the former over the latter until the anterior arch of the atlas is in front of the body of the axis. They may be bilateral or unilateral; in the former case, which is more rare, both articular surfaces of the atlas are displaced on those of the axis. *Dislocations backward* are of very exceptional occurrence. Malgaigne describes a case of Melchiori in which the autopsy showed the anterior ligament detached at the union of the atlas and axis, the capsular ligaments uniting the two vertebrae at their anterior part ruptured, the odontoid process fractured at the base and the posterior arch of the atlas fractured on both sides near the transverse processes. The patient had fallen forward forcibly, so that his forehead struck the ground. Owing to the rarity of these backward displacements, it is impossible to give a clear clinical picture.

The most common form of dislocation in this region is the *unilateral subluxation* or true dislocation occasionally or more often associated with a fracture. Of twenty cases of rotary dislocation collected by Corner, thirteen were described as unilateral, the dislocation being more or less complete, according to the degree of rotation. Cases of rotary displacement may be overlooked because of the absence in most instances of any signs of cord pressure. In Corner's series, excluding the two fatal cases, there were no paralyses at first; although symptoms of cord involvement frequently appear later, sometimes terminating fatally—as in Gibson's case, when the patient started to sit up and almost immediately fell back dead—sometimes, in the gradual onset of paralysis consequent upon a pressure myelitis. However, a diagnosis can be made by the pain and stiffness in the neck and by an examination of the pharynx, by the poise

of the head, by the displacement of the transverse processes of the atlas and by a skiagraph. If the pharynx be examined, with the patient under an anesthetic, two prominences may be detected: on the one side, the displaced transverse process; on the other, the "bulkier and less distinctly defined" (Corner) surface of the axis, uncovered by the displaced transverse process. The poise of the head is characteristic; in addition to being flexed the head is tilted to one side and the chin directed to the other. It may be possible to rotate the head a little toward the side opposite that in which the transverse process is dislocated.

In *bilateral dislocation,* rotary movements will be almost, if not entirely, restricted (Fig. 164). The transverse process may be palpable on the side away from which the head is deflected, but will be absent or indistinct on the other. The skiagraphic study is important not only as an aid to diagnosis, but in the management of the case. A lateral view should disclose the forward displacement of the transverse process, but in addition may, though not always, determine whether the odontoid process is fractured. This is a matter of great importance, since the risks of attempts at reduction are increased tenfold if the process be fractured, and, even without attempted reduction, sudden death may follow in greater displacement of the bones. If not fractured, the odontoid process prevents further displacement, as it locks with the anterior arch of the atlas and transverse ligament. In addition to the conditions already mentioned, difficulty in swallowing, paralysis of the hypoglossal nerve and hemi-atrophy of the tongue have been mentioned as coincident symptoms.

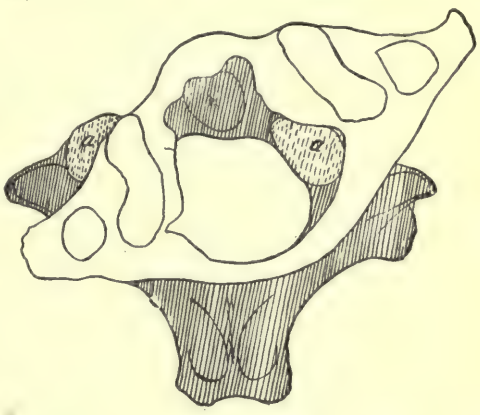

FIG. 164.—DRAWING SHOWING ANTERIOR DISPLACEMENT OF THE RIGHT SIDE OF THE ATLAS (UNSHADED) ON THE AXIS (SHADED). (Corner.)

X indicates the odontoid process and *a*, *a*, superior articular facets of the axis.

The management or mismanagement of rotary dislocation of the atlas may result in complete paralysis or sudden death. Decision for or against an immediate attempt at reduction will depend upon the condition of the odontoid process. If a fracture has been demonstrated or can be suspected, it is the better part of prudence to immobilize the parts for a month, and not until then attempt reduction. In attempting reduction, muscular relaxation is desirable; the patient is anesthetized and with the slightest manipulation, traction and rotation, the bones may be replaced. A fixa-

tive dressing in the form of a plaster of Paris or celluloid collar should be worn for at least three months after reduction, and without reduction some appropriate appliance should be worn indefinitely. It is conceivable that pressure symptoms may require a decompressive laminectomy for their relief, although I have never been called upon to operate under such

FIG. 165.—A DISLOCATION OF BOTH ARTICULAR PROCESSES OF THE ATLAS UPON THE AXIS. SUICIDE BY HANGING. (Allen.)

circumstances. A rather interesting operative experience was reported by Mixter, who operated upon a boy fifteen years of age with recurrence of pain in the distribution of the occipital nerves, caused evidently by the slipping forward of the atlas. The odontoid process was fractured and showed no tendency to unite. An attempt made at reposition was only partially successful. This was maintained and the atlas anchored by a band of stout braided silk, which was passed about the posterior arch of

the atlas and fastened about the spinous process of the axis. An apparatus was worn for two months only and two years after the operation there had been no recurrence of symptoms. This dislocation is a frequent sequence of hanging and the accompanying illustration is a specimen from a case of suicide by this means (Fig. 165).

Dislocation of Other Cervical Vertebrae.—For anatomical reasons, dislocations of the lower six cervical vertebrae are the most common; in fact, it is doubtful whether pure dislocation without fracture can occur at a lower level, i. e., in the thoracic or lumbar vertebrae. The sites of predilection are the articulation between the fourth and fifth and between the fifth and sixth vertebrae. According to the mode of transmission and violence of the injuring force, dislocations may be classified as (*a*) bilateral forward, (*b*) bilateral backward, (*c*) bilateral in opposite directions, and (*d*) unilateral forward. In accordance with the oft-quoted statistics of Blasius, of 108 cases of dislocation in this region, 23 were diastases, 41 bilateral dislocations forward, 37 unilateral forward, 4 bilateral in opposite directions, and 3 bilateral backward. The bilateral forward and the unilateral forward are the usual, the others the exceptional dislocations. (See also Fig. 102.)

Fig. 166.—Luxation of the Fifth Cervical Vertebra. (Wagner and Stolper.)

The mechanism of *bilateral forward dislocation* is one of anterior hyperflexion, although it has been said that posterior hyperflexion or even direct violence may be the determining factor. As a matter of fact, in all instances under my observation and others of which I have knowledge, the dislocation followed violent forward flexion of the head on the chest, in two instances in the course of a wrestling contest and in one while diving in shallow water—a not infrequent cause. The capsules and posterior ligaments are the first to give way and, as the flexing force continues, the antero-inferior edge of the body of the upper vertebra slides in front of the upper border of the vertebra next below, and the articular surface of the upper vertebra is carried forward to the point of separation from the articular surface just below. The antero-inferior body acts as a fulcrum and this brings tremendous pressure on the anterosuperior lip of the body just below. Apart from the rupture of the capsular ligament, the interspinous ligament, the ligamenta subflava are torn, also the inter-

vertebral disk. There may be associated fractures of the spinous processes and laminae, and what is of greater significance, the spinal cord itself is almost irreparably damaged, either from compression or overstretching. This type of dislocation occurs most often between the fifth and sixth cervical vertebrae (Fig. 166). In Quetsch's series of cases, it was located six times between these two vertebrae, twice between the sixth and seventh cervical, and once between the fourth and fifth. This dislocation, bilateral dislocation forward, is not so readily recognized because of the various positions assumed by the head, which depend upon the direction of the injuring force and the accompanying rupture of the ligaments. To be sure, in most cases the head is bent forward on the chest (Fig. 167) and the spinous process of the vertebra next below is prominent, but occasionally the head is bent backward, with or without lateral inclination; in the upper four cervical vertebrae, the prominence may be detected in the pharynx, and the larynx and trachea may be projected forward. In thin subjects, one may feel a break in the alignment of the transverse processes, whereby those of the spinal segment above the dislocation lie anterior to those below. Sometimes a dislocated vertebra is somewhat tilted so that not only is the face inclined to one side, but there is a deviation of the transverse process from the median line. Movement of the head in any direction, if possible at all, will be resisted because of the accompanying pain. There may be voluntary or involuntary fixation of the head, or, to put it another way, the head may be immobile or mobile. The former condition may be the result of voluntary or involuntary muscular contraction; the latter implies usually extensive ligamentous injuries and associated fractures.

FIG. 167.—FRACTURE-DISLOCATION OF PROBABLY THE FIFTH CERVICAL OR THE SIXTH. (Scudder.)

Head assumed this position immediately after a fall downstairs.

In total dislocation forward, the prognosis is extremely grave; the damage to the cord is usually irreparable and death ensues in the course of a few days. That total dislocation of the cervical vertebrae may be unattended with cord injury was once questioned, but enough evidence is now on record to convince us that exceptionally such may be the case. A striking example of this has been recorded by Beusch, whose patient, a

woman, fell head foremost from the top of a hay wagon. For a few moments she lay stunned on the ground and upon recovering consciousness complained of severe pain in the neck and inability to move her head from a position of marked flexion. There was no evidence at any time of cord injury. The patient was kept in bed for two weeks and then resumed her routine duties. Occasionally, however, when she pushed her head upward, she experienced pain in the back of the neck and a tickling sensation in the hands. These subjective phenomena were never spontaneous and followed only futile attempts to carry the head upward. The roentgenogram showed a total forward dislocation of the fourth cervical vertebra (Fig. 169). Between the time of the accident and until the operator is ready to reduce the dislocation, it is desirable that a temporary fixation dressing be applied, moderate extension or sand bags, and the head should lie on the bed rather than on a pillow, to avoid flexion. A restraining dressing should be applied and maintained for eight weeks, or even longer if its removal be accompanied with pain.

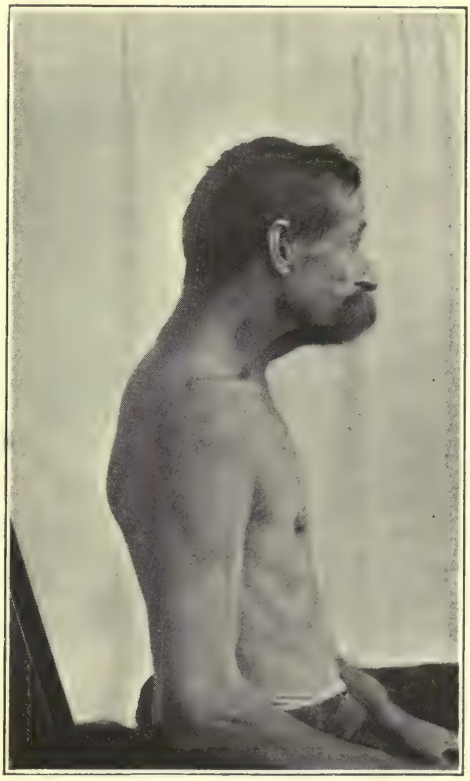

FIG. 168.—LUXATION OF CERVICAL VERTEBRAE WITHOUT CORD SYMPTOMS.

Reduction of dislocation forward is accomplished by extension to overcome the action of ligaments and muscles, with or without pressure. The patient should be placed upon an operating table with the head and neck projecting beyond the edge of the table, and properly supported in the hand of a surgeon. The assistant makes counterextension by traction upon the shoulders. In this position, with the head slightly fixed and resting in the palms of his hands, the operator makes traction upon the head until, with slight pressure over the spinous process of the projecting vertebra, the deformity is reduced. Care must be taken to make traction directly in the axis of the body or the axis of the spinal canal, avoiding either directly backward or forward flexion. These two positions are to be avoided under all circumstances, but more especially when traction is not made, as it will

expose the cord to pressure or laceration. When sufficient traction has been made to disengage the joint surfaces and articular processes, the bones usually return to the normal relations, though occasionally slight pressure upon the head from behind may be necessary. There are a few instances in which reduction by this method was impracticable but was attained by the method of Hueter which attempts to reduce first one side, then the other.

In *unilateral rotary dislocation forward,* the next most common dislocation in the cervical region, but one of the articular surfaces is dislodged, as the term implies, the other remaining in place. This dislocation, as the others of the cervical region, may be caused by a blow or fall upon the head, or more particularly by forcible twisting of the head, as may happen in wrestling. It may be caused by direct or indirect violence, or by muscular action. The movement is essentially one which carries beyond the physiological limits the normal movements of abduction and rotation. The lumen of the spinal canal is but little encroached upon and the spinal cord may readily escape serious injury. There is a slight dislocation of the spinous process toward the side of the disarticulated process and the body of the dislocated vertebra projects slightly over that immediately beneath. Clinically this variety may be suspected if the head be maintained in a position not unlike that of torticollis. When the dislocation is so complete that the transverse process of the dislocated vertebra lies in front of the transverse process of the vertebra immediately beneath, the head is almost invariably inclined to one side (Fig. 170). The diagnosis is confirmed by the deviation of the spinous process from the median line, by detecting in the

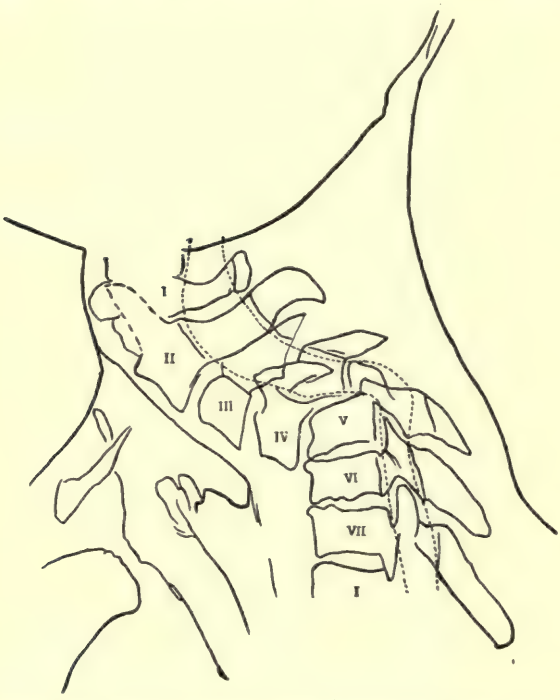

FIG. 169.—TOTAL DISLOCATION FORWARD. (Beusch.)
The antero-inferior edge of the body of the upper vertebra (fourth cervical) slides in front of the upper border of the vertebra next below.

pharynx the projected body of the dislocated vertebra, at least as far down as the fifth cervical vertebra, and by the presence of a painful prominence on the affected side, which Volker attributes to the altered position of the transverse process. The processes are more prominent and deflected to one side above the level of the dislocation. In many instances, however, some of these signs may fail and the diagnosis be confirmed only by the roentgenogram. Thus, it may not be possible to detect the deviation of the spinous process, as when the spinous processes are deep-seated, and the torticollis position may not be apparent because the deformity may be compensated for by the flexion of the occipito-atlantoid articulation and by rotation in the articulation between the axis and the atlas.

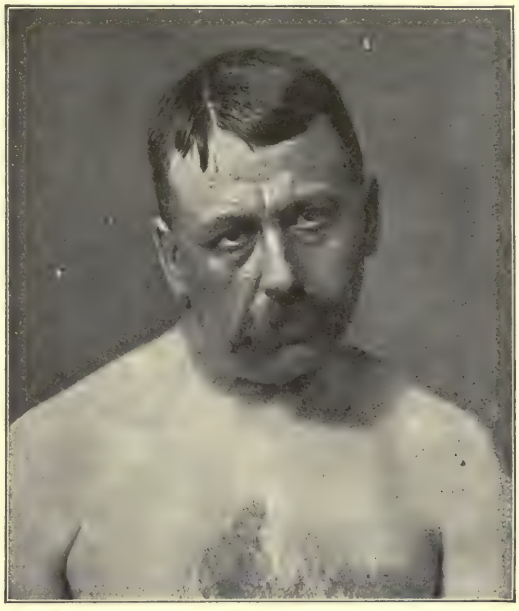

FIG. 170.—DISLOCATION OF RIGHT ARTICULAR PROCESS. (Walton.)

Ordinary form, in which the process has slipped way over; head is, therefore, to the left and bent to the right; the sternomastoid muscle is tense on the left, lax on the right.

Reduction of the unilateral dislocation is effected chiefly by a process of rotation and abduction. In other words, the usual deformity is exaggerated: if, for example, the head be rotated toward the left the rotation is carried still further; if there be slight lateral abduction toward the opposite side this is increased. In this position very slight traction will disengage the articular processes. To facilitate the reduction the patient may be placed in the recumbent or in the sitting posture. The fact that spontaneous reduction has taken place is rather an argument against the necessity of traction in the process of reduction. Furthermore, Walton found that no amount of extension or traction would dislodge the articular process from its new position, even after the capsular ligament had been divided. When the head was extended diagonally backward toward the side of the convexity, the articular process was readily elevated and rotation restored the normal position. Upon reduction the head and neck should be restrained with an appropriate collar to be worn two months, or still longer if upon its removal unrestrained movements of this segment of the spine give rise to pain.

The prognosis of unilateral dislocations forward is on the whole more

favorable because the spinal cord is not subjected to the same degree of pressure as in bilateral dislocations, although both, from hemorrhage and contusion or overstretching the function of the cord, may be disturbed sufficiently to give rise to varying degrees of anesthesia and paralysis.

In *bilateral dislocation in opposite directions* the mechanism corresponds to that of unilateral dislocations forward, namely, abduction and rotation. By a continuation of the force, the opposite inferior articular process is displaced more or less backward, with rupture of the capsule. In addition to the dislocation, the lower border of the articular surface of the disarticulated vertebra may be chipped off. But few instances of this dislocation are on record, the first appearing in the classical essay on dislocations by Malgaigne. The precise nature of the injury can be determined only by the roentgenogram, together with such physical signs as are common to the unilateral variety. Without the roentgenogram, differentiation between these two types would be difficult, if not impossible. Theoretically, at least, the head should be more constantly in rotation, with or without abduction. In reducing this dislocation, the same principles as apply to the unilateral type may be applied; that is, rotation and abduction, reducing the dislocation first on one side and then on the other. Similarly, after reduction, an immobilizing dressing should be applied.

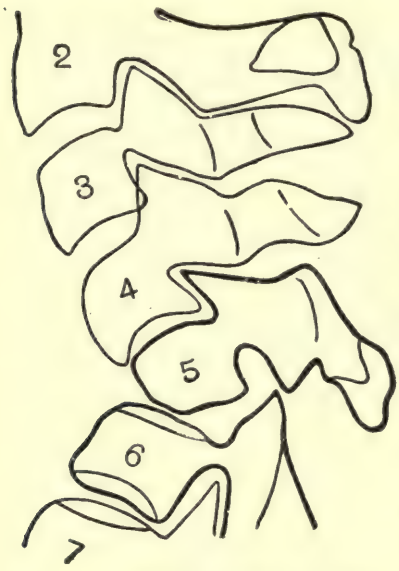

FIG. 171.—TOTAL BACKWARD DISLOCATION OF THE FIFTH CERVICAL VETEBRA. (Quetsch.)

Bilateral dislocations backward are relatively infrequent and from the few recorded cases it would seem that the mechanism involves sharp flexion of the neck forward and direct backward pressure. The antero-inferior edge of the dislocated vertebra engages the superior surface of the underlying vertebral body, and as the force is increased the capsular ligaments are torn, the intervertebral disk ruptured and the body of the affected vertebra is dislodged. However, in Stanley's case, a backward dislocation of the fifth cervical vertebra, the injury followed a fall backward upon the head and back.

In Quetsch's case, one of the few cases of total backward dislocation, a woman, nineteen years old, fell a distance of only three meters, striking the head (Fig. 171). Immediately after the accident, there was voluntary fixation of the neck and head; any attempt at movement, especially to the left, was extremely painful; the left arm was paralyzed; her gait was

unsteady; and the tendon reflexes were exaggerated, although bladder and rectum were undisturbed. About two months after the accident, when first seen by Quetsch, the posture of the head was normal, movements of the head were unimpeded, but the spinous process of the fifth cervical vertebra was prominent, though not painful on pressure. There were no disturbances of the nervous system other than exaggeration of the patellar and Achilles tendon reflexes. The roentgenogram taken at the time confirmed the diagnosis, and another taken eight months later showed a mass of callus filling in the space formerly occupied by the dislocated vertebra, and establishing osseous union between the dislocated vertebra and the one immediately below. Backward dislocation of the cervical vertebrae does not present so characteristic a picture as those of the preceding types, the bilateral forward and the rotary. In most of the recorded cases, the head is tilted backward, the face upward, the patient may complain of difficulty in swallowing and the spinal cord symptoms may be those of a complete or incomplete lesion.

Diastasis of the cervical vertebrae is, I believe, a not uncommon lesion, relatively speaking. Many cases of this, no doubt, have been diagnosed and grouped as fractures of one or the other bony processes, but when such an injury is attended with a complete, or, at least, a grave cord lesion, the injury to the cord has been inflicted by the displacement of one vertebral body. By the time the patient is examined, there is no apparent displacement of the vertebral bodies—a fact confirmed by the roentgenogram which may or may not show some inconsequential fracture of a transverse or spinous process. The cord is pinched at the time of the accident and frequently the lesion is a serious one. I have seen a typical instance of diastasis of the cervical vertebrae where the mechanism was that of acute flexion, as in a wrestling match, and in most cases the mechanism is similar to that of a forward dislocation; but a rather unique example of diastasis by muscular action was that occurring in a crazy man who, as told by Lasalle, while sitting in his strait-jacket, jerking his head violently forward and backward, suddenly became paralyzed and in a few hours was dead. In this extraordinary case the diastasis was found at autopsy to be between the fifth and sixth cervical vertebrae and accompanying the diastasis were lacerations of the muscles and ligaments, interspinous and subflava. The following is a case of cervical diastasis which recently came under my observation:

In the course of a wrestling match the patient's head was acutely flexed on the thorax. Complete transverse lesion. Slight deviation of the fifth spinous process but no fracture or dislocation. Injury of cord attributed to diastasis.

The patient, a man, *aet.* 18, was seen the day after the accident. The previous evening, while wrestling, he picked up his opponent and threw him on the floor, and in so doing the patient's head was caught under the arm of his opponent,

and, according to eye witnesses, acutely flexed on the thorax. At all events, immediately after the throw, the patient was found to be completely paralyzed in both arms and legs, with loss of sensation from the level of the second intercostal space down. In the course of the night he complained of a good deal of pain in the right arm. He was admitted to the hospital at eleven o'clock the following morning and examined by me at three o'clock in the afternoon, within eighteen hours of the accident. There was complete paralysis of both the upper and lower extremities and total loss of all reflexes. The abdominal walls were tense; there was complete anesthesia for all forms of sensation from the level of the second intercostal space down, with the exception of an area on each shoulder, which corresponded to the outlines of the deltoid muscles. The pupils were both contracted so that it was almost impossible to tell whether they responded either to light or distance. The patient was mentally dull, rather drowsy, although he answered all questions addressed to him. Upon examination of the cervical spine, an area of marked tenderness was found over the spinous processes of the fifth and sixth cervical vertebrae. The alignment was perfect and there was no preternatural mobility or crepitus; respiration was entirely diaphragmatic, and the temperature 105° F. There had been complete retention of urine. The roentgenogram showed some slight deviation to the left of the spinous process of the fifth cervical vertebra, but the bodies of the vertebrae were neither broken nor dislocated. If there were any fractures of the processes, they were inconsequential.

Résumé: The evidence pointed to a complete transverse lesion of the cord, the symptoms developing immediately after an injury in which the head was acutely flexed on the chest. The absence of dislocation of the vertebrae or a fracture of the vertebral bodies, with complete loss of cord function suggested a diastasis and a temporary disarticulation of the vertebral body with crushing or pinching of the cord. There were no indications for operative intervention in the absence of any evidence of deformity, pressure or hemorrhage.

Dislocations in the Thoracic Region.—Compared with dislocations of the cervical region, dislocations of the thoracic vertebrae are not common. As elsewhere in the spinal column the cause may be either indirect violence, as from acute flexion, or direct violence, as from the blow of a heavy object such as the weight of a wagon wheel.

In the Blasius series there is a collection of 39 cases, of which 22 were confirmed at autopsy, situated as follows:

Confirmed by Autopsy	Thoracic Vertebra	Doubtful
0	I	0
0	II	0
1	III	0
0	IV	0
3	V	1
1	VI	0
0	VII	0
0	VIII	1
1	IX	0
3	X	1
2	XI	4
11	XII	10
22		17

The site of predilection for thoracic dislocation is, as one might expect, at the junction of the thoracic and lumbar vertebrae. While the relation of the various processes at this level would not predispose toward a luxation, the thoracic vertebrae from the first to the ninth are given a measure of support from the ribs which is not enjoyed by the tenth, eleventh and twelfth. So that in the 39 cases of Blasius' collection 27 involve either the eleventh or twelfth, and 21, or more than half, the twelfth alone. All the varieties of dislocation described elsewhere have been observed—forward, backward and rotary, unilateral and bilateral—the forward with no greater frequency than the backward dislocation.

There is nothing distinctive in the symptomatology of thoracic dislocation; in fact, in many cases it is difficult to differentiate a dislocation from a fracture without the aid of the roentgenogram. There may be in both a prominence of the spinous process, perhaps more pronounced in dislocation; in the rotary type of dislocation, the deviation of the spinous processes from the median line; the articular process may be more readily palpable beneath the skin; there may be a fracture or dislocation of the adjoining ribs; and according to the damage to the cord, more or less functional disturbance. Recovery with or without loss of function has been recorded in a certain number of cases and many have terminated fatally. Generally speaking, the higher the dislocation the more grave the prognosis. What has been said elsewhere of the advantages of the open over the closed method of reduction applies with equal force here. While in certain instances reduction has been effected by extension and counterextension, in certain cases the attempt has failed, and in these, if not in all, the open method should be resorted to. A fixation dressing should be applied and continued until the repair of the ligamentous structures safeguards against recurrence.

Dislocations of the Lumbar Vertebrae.—Dislocations of the lumbar vertebrae are exceedingly infrequent, particularly if one should eliminate those in which there was an associated fracture of one process or another. Thus, in one of Decker's cases there was also a fracture of the vertebral body. With the exception of Borchard's case I have been unable to find any example of a complete luxation of the lumbar vertebra without fracture, and as the findings of this case were verified at operation the evidence is thoroughly trustworthy. In the case of Keig there were fractures of the ninth, tenth and eleventh spinous processes, the right lower articular process of the second lumbar vertebra and the left transverse processes of the first and second lumbar vertebrae. Borchard's case (Fig. 172) seems to be the only example of uncomplicated total luxation of the lumbar vertebra, but if we include those associated with inconsequential fractures, there must be included the cases of Keig, Cloquet, Porter, Curling and Schmid.

The infrequency of lumbar dislocations may be attributed to a num-

ber of anatomical factors. Unlike the cervical region where dislocations are most common, there is a comparatively limited range of motion in the lumbar region, the bodies of the lumbar vertebrae are much larger in every dimension, the intervertebral disks thicker and more elastic, the ligaments at this level of the spine have great strength, and finally—what is probably a factor of greatest importance—the articular processes interlock. Those of the upper vertebrae so interlock with those of the vertebra underlying that separation is almost impossible without fracture.

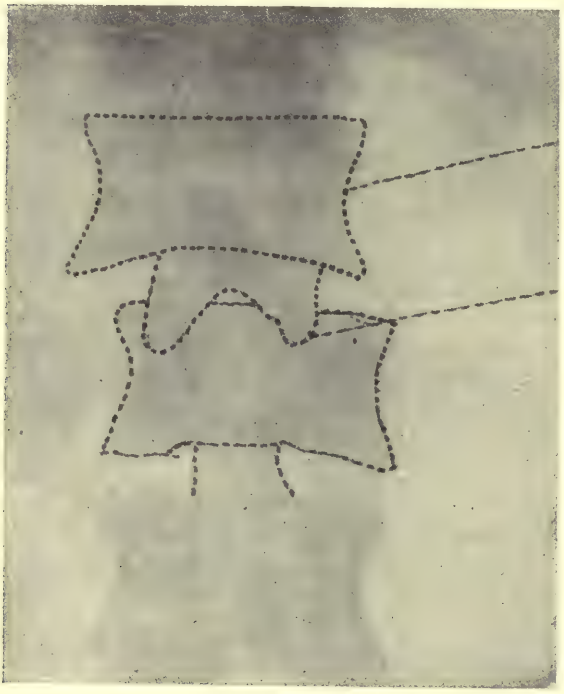

FIG. 172.—LUXATION FORWARD OF THE FIRST LUMBAR VERTEBRA. (Borchard.)

The articular processes (2) of the first lumbar vertebra (1) are in front of the body of the second lumbar vertebra.

The mechanism of luxation of the lumbar region is an exaggeration of the lumbar lordosis by a direct force forward. In one instance it may be that the patient is run over by a wagon (Borchard), in another a heavy object may fall upon the subject lying face down (Decker). In the case of Keig a heavy iron cylinder fell across the patient's back. So far as I know all the cases of dislocation of the lumbar vertebrae with one exception have been either backward or forward. In the exceptional case, a rotary dislocation (Schmid), as seen in the roentgenogram, the second or proximal vertebra projected to the right 1.5 cm. beyond the third or distal vertebra, and the alignment of the spinous processes had not been disturbed. There was a fracture of the inferior articular process on the left side and fractures of the eleventh and twelfth ribs. At the examination six weeks after the accident the body was held in slight flexion, the lumbar lordosis was obliterated. The lower half of the thorax on the right side projected somewhat, but the relation of the spinous processes to each other had not been disturbed. There was pain on pressure over the spinous processes of the first three lumbar vertebrae and arching of the spine forward or to the side was impossible.

The symptoms of lumbar dislocation may be gathered from the few recorded cases. There are in all the localized pain and tenderness, the disability, the disalignment of the spinous processes and the evidence of injury to the cord or cauda equina. In some instances the normal lordosis of the lumbar region is obliterated and in many there are associated injuries which of themselves may prove fatal. Whether because the cauda less completely fills the canal or because the roots of the cauda can better accommodate themselves to the contracted space, there is less evidence of damage to the cord in dislocations of the lumbar than in those of the thoracic or cervical region. Even in total dislocation the cord may escape irreparable injury. The immediate effect of the injury to the cord may simulate symptoms of a complete transverse lesion. If the cord be overstretched and its circulation temporarily interfered with, the evidence may suggest a transverse lesion, but the persistence of some form of sensation may be accepted as conclusive evidence that some function of the cord has been preserved. Hence it is wise not to attempt to pronounce the prognosis too soon after the injury. In the analysis of six cases of dislocation of the lumbar vertebrae, three were recorded as improved and two as having recovered, one with and one without operation. In three there was an incomplete cord lesion and in three there was no involvement of the cord at all. The injury was one of direct violence in two instances and indirect in the others.

The management of dislocations of the lumbar vertebrae, as of dislocations in other segments of the column, is a matter for discussion. One must decide in the first place between open and closed reduction or between an attempt or no attempt at reduction. There is not in lumbar dislocation the danger of sudden death in an attempted reduction, so that when the function of the cord is impaired no doubt should arise as to the prudence of attempting reduction. While most surgeons advocate the closed method of reduction, I am strongly of the belief that, all things taken into consideration, the open method is the safer. And with this opinion I find Borchard is in entire accord. He believes, as I do, that when the cord function has not been altogether lost there is a better chance of protecting the cord against further damage by the open method. What is of even greater significance, he found on the operating table, in a case of lumbar dislocation, the futility of extension and counterextension applied to head and foot as an aid in disengaging the vertebral bodies. This explains the difficulty encountered in the attempts at reduction by the closed method, although not all have been attended with failure. The patient should be anesthetized, and placed in the prone position with a cushion beneath so as to arch the spine. With or without extension and counter-extension, for these seem of little value, pressure is made directly over the spinous process of the dislocated vertebra.

Treatment of Dislocations.—Immediate reduction is the ideal treat-

ment of all recent dislocations of the vertebrae. The general dictum is made, however, with certain reservations. The propriety, for example, of attempting reduction of a cervical dislocation when there is little or no involvement of the cord might well be questioned because of the possibility of sudden death or of cord pressure during the attempt at reduction. On the other hand, while the persistence of the deformity is not inconsistent with life and activity, there is always the risk of the consequences of gradual or sudden displacement. Immediate reduction is of course desirable, and yet there are on record cases in which there has been restoration of function when reduction was not accomplished for from one to eight weeks after the accident. No doubt, in many instances, irreparable damage to the cord has been inflicted at the time of the accident, and though reduction has been successfully accomplished, the cord symptoms persist.

To my mind, the most vital question in the management of dislocation is whether the open or closed method should be employed in the first instance. The possibility of sudden death during attempted reduction is admitted; surgeons are advised to inform the patient or family of this risk, and, thus relieved of responsibility, they proceed to attempt reduction by the closed method. When the facilities for the performance of a laminectomy under every safeguard are not at hand, the closed method will be safer and, therefore, should be endorsed. While not wishing to recommend a practice that in inexperienced hands might end disastrously in many cases, I want to establish this point: that the open method of reduction should not be reserved always for old luxations or only after ineffectual attempts by the closed method, but should at least be given due consideration in every case and preference may be given it after the relative merits of the two procedures have been fully disclosed.

The additional risk of pulmonary complications, which might be advanced as an argument against ether narcosis, may be avoided by substituting infiltration anesthesia with nitrous oxid-oxygen anesthesia—a perfectly practicable proposition. The comparative safety with which we can perform an exploratory laminectomy should make us question the conservative practice of the past. Apart from the risk of sudden death, there is in not a few cases a reasonable doubt as to the nature of the lesion which has rendered the cord functionless, and its precise nature can only be determined by the open method. Thus, in a case of subluxation of the twelfth thoracic vertebra with complete paralysis of the lower extremities and loss of rectal control, Harrison attributed the cord lesion to a displaced vertebra. A week after the injury an exploratory laminectomy revealed, in addition to the torn ligaments and displaced vertebra, an epidural clot, the removal of which was followed within a few days by signs of improvement and ultimately by the patient's return to active military service.

In a case of dislocation of the lumbar vertebra, Borchard deliberately chose the open method in order to protect the cord against further damage. Function was only in part lost, and, fearing complete abolition should the cord be injured in the process of reduction, he selected the open method and advocates it with considerable enthusiasm. With the unusual experience Borchard has had in neurological surgery, his opinion demands every consideration, and is quite in accord with my own. Surely, if the open method is to be preferred in dislocations of thoracic or lumbar vertebrae, it has a wider field and more urgent application in dislocations of the cervical vertebrae. This position, admittedly radical, is evidently not approved by many, at least, judging from the cases reported within the past five years. Of forty-nine cases, there were but two immediate operations with one recovery and one death from shock.

TABLE I

	Immediate Operation	Late Operation	No Operation	Total
Recovery	1	1	7	9
Improved	..	5	22	27
Unimproved	..	..	4	4
Immediate death	..	..	2	2
Subsequent death	1	..	4	5
Not stated	..	..	2	2
Total	2	6	41	49

Of those treated without operation, there were 6 deaths—a mortality rate of about 15 per cent—which, taking into consideration the nature of the lesion itself and the frequent complications, is surprisingly low.

The methods of reduction must be varied according to the location and the type of dislocation, whether forward, backward, rotary, unilateral or bilateral. The several procedures have been discussed separately as applied to cervical, thoracic and lumbar luxation. Under all circumstances the reduction should be attempted under general narcosis; the avoidance of pain and the relief of muscular spasm are desirable. As the bone is restored to its place there is a peculiar snapping sound readily recognized by the surgeon. After reduction of cervical dislocations, the head and neck should be immobilized with a light plaster or gypsum dressing, or wire splints. The patient should be kept in bed under restraint of a fixed dressing for two or three weeks, that is, until ligamentous repair be reasonably well advanced, and after that a suitable brace should be worn continuously during the day for the next three months (Fig. 173). When efforts at reduction fail, some form of fixation dressing is to be

applied and worn continuously until the repair of the damaged articular structures has been accomplished and the danger of further displacement averted.

The management of old dislocations is a matter of some moment. After two or more weeks have elapsed and ligamentous repair is fairly well advanced, I doubt the wisdom of attempts at reduction, even though a few cases have been reported in which there has been return of function following reduction after the lapse of eight weeks. In dislocations associated with fracture the formation of callus would make attempts at forcible reduction by the closed method, to my mind, prohibitive and before any decisive action is taken a careful study of existing conditions should be made with the roentgenogram. Admitting the inadvisability of attempting reduction by the closed method in old dislocations, the question next to be considered is whether an open operation is desirable. Exploratory operation is indicated when there is evidence of continued functional disturbance of the cord, but only in comparatively recent cases and whenever there is reason to believe the symptoms consequent to pressure or traction upon the roots. These are the circumstances when an exploratory laminectomy may be desirable.

FIG. 173.—COLLAR TO BE WORN AFTER DISLOCATION IN THE CERVICAL REGION. (Beusch.)

But operative treatment may be distinctly indicated in old dislocations for other reasons. Many cases of luxation of the cervical vertebrae, either because of pain, of a sense of insecurity, or of the fear of greater displacement, in some instances real and not imaginary, wear some appliance to make the ligaments more stable, to relieve pain and to prevent the head dropping forward. These appliances are more or less cumbersome, therefore, not welcome, and restrict to a considerable degree the movements of the head. As substitutes for these, several procedures have been proposed: silver wire by Chipault, periosteal flaps by Cabot, periosteal bone-flaps by Vulpius, but preferable to all of these is the Albee bone-graft, first applied to old luxations by de Quervain, who, taking the spine of the scapula as his graft, transplanted it in two cases of old dislocation of the fifth cervical vertebra. The outcome in both cases was more than satisfactory to the patients, the apparatus was discarded, the newly provided support quite adequate and the movements of the head curiously enough were freer after than before the operation.

Prognosis.—The prognosis of dislocations of the vertebrae is grave. Naturally, the higher the lesion the graver the prognosis, and inasmuch

as the vast majority of dislocations of the vertebrae are in the cervical region, a higher rate of mortality is recorded than were the cases more evenly distributed in the lower levels. Many dissertations on this subject quote the statistics from the series of 278 cases collected by Blasius in which the percentage of recoveries was 22.6, the mortality 87.4. In at least 27 of the 36 recoveries reduction was complete, thus illustrating the importance of reduction at the earliest possible moment.

I have collected from literature dislocations that have been reported during the past five years, of which number there are approximately 49 distributed as seen in Tables II, III and IV. Of this series there were but 2 cases of immediate death and 5 cases of subsequent death; that is, an immediate mortality of 4 per cent, and an ultimate mortality of 10 per cent. Although the series is small, the mortality as compared with Blasius' collection is very much lower. An attempt was made in this statistical study to determine the relative percentage of recoveries in those which were operated upon, either early or late, and those which were not operated upon, but of the total number of cases there were but two immediate operations—a number so small as to be of no statistical value (Table I).

Speaking from the standpoint of complete recovery as contrasted with recovery with impairment of function, we find in our series (Tables II, III and IV) that there were 20 per cent of complete recoveries as compared with 50 per cent of those who recovered with more or less impairment of function. Naturally, the prognosis is better in the unilateral variety than in the bilateral variety. One can never be quite sure, however, at the time of the accident or shortly afterward to what degree the cord is damaged. It is because of this uncertainty that early exploratory operation or the attempt at reduction by the open method has been so strongly advocated. I can recall a case under the observation of Hill where there was every reason to believe that the patient had a serious if not complete lesion of the cord. The operation was performed four days after the accident, the laminae of the seventh cervical and first thoracic vertebrae being removed. An unrecognized forward dislocation of the sixth cervical vertebra was found and reduced. Improvement was almost immediate; the priapism disappeared, sensation in the bladder returned, and little by little there was recovery from what had been a complete paralysis of the lower extremities. There are on record a certain number of cases, a few isolated histories, in which reduction of the dislocation has been spontaneous. In one of these Warren made a careful effort at reduction under ether but without success. The patient was then sent from the hospital to a convalescent home, and one day while sitting in a warm bath and having cold water poured down his back he felt as though an electric shock passed through him and simultaneously his head recovered its normal position and the paralysis rapidly disappeared.

TABLE II

CERVICAL REGION

	Transverse Lesion	Incomplete Lesion	No Cord Involvement	Unclassified	Total
Recovered	..	3	4	..	7
Improved	2	18	4	1	25
Unimproved	..	1	3	..	4
Immediate death	2	..	..	..	2
Subsequent death	4	..	..	1	5
Not stated	1	..	..	..	1
Total	9	22	11	2	44

TABLE III

LUMBAR REGION

Recovered	..	2	..	..	2
Improved	..	1	1	..	2
Unimproved	..	..	..	..	..
Immediate death	..	..	..	..	..
Subsequent death	..	..	..	..	..
Not stated	..	..	1	..	1
Total	..	3	2	..	5

TABLE IV

(SUMMARY OF TABLES II AND III)

Recovered	..	5	4	..	9
Improved	2	19	5	1	27
Unimproved	..	1	3	..	4
Immediate death	2	..	..	..	2
Subsequent death	4	..	..	1	5
Not stated	1	..	1	..	2
Total	9	25	13	2	49

In a consideration of the prognosis one must also bear in mind the possibility of sudden death either during the attempts at reduction or at some time subsequent thereto when reduction has not been accomplished and inadequate fixation has been provided.

ISOLATED FRACTURES

Spinous Process.—While isolated fracture of the spinous process, like that of the arch, is usually the result of direct violence, extreme muscular exertion may be the causative factor in many cases (Schulte, Gümbel, Küttner, von Frisch, Heuschen, Sauer, Skillern, Riedinger and others). In Skillern's case the sudden contraction of the rhomboidei minores muscles, in the lifting of a heavy object from the ground, resulted in a fracture of the spinous process of the first thoracic vertebra; Schulte's patient illustrates the part muscular action plays in an isolated fracture of the spinous process in the lumbar as well as in the cervical and thoracic regions, and von Kryger's experiments on the cadaver have shown that posterior hyperflexion of the vertebral column may cause fracture of the spinous processes of the lumbar vertebrae. In Schulte's case a soldier while bending forward preparatory to jumping experienced severe pain in the lumbar region, and a little later an abscess formed over the third lumbar vertebra; two weeks after the injury the abscess was opened and a piece of the broken spinous process 1.5 cm. long was removed.

Fractures of the spinous process of one or more vertebrae are much more frequently seen in association with dislocations and fracture-dislocations, or fractures may occur alone, as in the case of a man 42 years of age who, falling from a height, sustained a compression fracture of the body of the sixth cervical vertebra together with its spinous process. There was no positive evidence of cord injury, but the patient complained of pain and a feeling of heaviness in the right shoulder and arm. Relatively speaking, isolated fracture of a spinous process is infrequent, although, as with other outlying processes, the number of cases has increased since the x-ray has been employed routinely as an aid to diagnosis.

The level of the fracture depends somewhat upon the character of the injury, whether by direct or indirect violence. However, the most common location is in the cervical and upper thoracic regions (Fig. 174). The short spinous processes of the upper cervical region and the strong processes of the lumbar region render them less exposed to fracture. The line of fracture may be oblique or vertical, rarely horizontal, sometimes at the tip and sometimes at the base of the process. In Wagner and Stolper's collection seven cases of isolated fracture of the spinous processes of the thoracic and lumbar vertebrae are mentioned; in three several processes were broken and in four only one. Often there is no displacement, as the fracture is seldom complete; but when there is, the fragment is displaced downward or to the side, as in Küttner's case of fracture of the spinous process of the fourth lumbar vertebra with displacement to the right. In uncomplicated cases the cord and roots are never involved and the prognosis, therefore, is exceedingly good.

The symptoms of isolated fracture of the spinous processes are pain, localized tenderness, crepitus and preternatural mobility. The pain may radiate to neighboring structures, causing limitation of motion; when the fracture involves a spinous process of the cervical or upper thoracic regions, there may be voluntary restraint of movements of the shoulders and arms, and if in the lumbar region, restraint in flexion of the thigh. Crepitus and preternatural mobility are readily detected; the roentgenogram reveals the line of fracture and the process may be displaced downward a distance equivalent to its own diameter, so that the interval between it and the spinous process immediately below will be obliterated. Should there be evidence of cord injury one should look for a fracture of the laminae or some other lesion to account for it. During the course of union the formation of callus makes the process broader and thicker than before the injury.

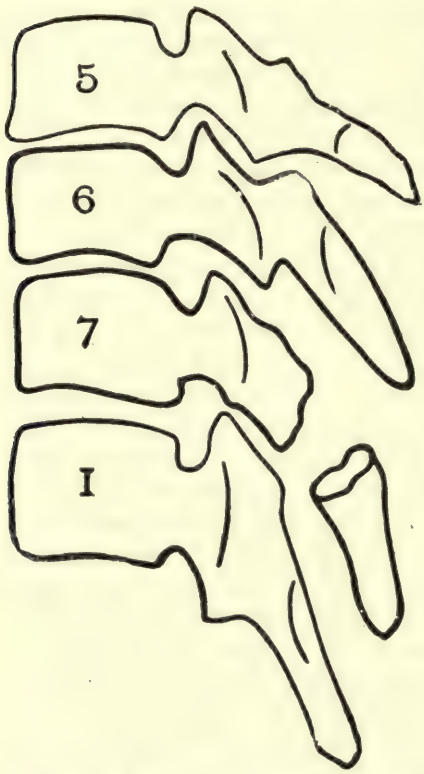

FIG. 174.—VERTICAL FRACTURE OF THE SPINOUS PROCESS OF THE SEVENTH CERVICAL VERTEBRA. (Quetsch.)

Fracture of the spinous process should not of itself give rise to more than transitory disability. As an associated lesion of a serious sprain or some more serious skeletal injury, its prognosis would be more grave. But with isolated fracture alone the patient should be able to resume his occupation within a few days or at the most a few weeks. Although the prognosis as to functional recovery is excellent, fibrous rather than bony union is the rule. In the exceptional case, as a result of downward displacement, a pseudo-arthrosis may develop; four examples of this were recorded by Gurlt. There are two deaths recorded—one by Schulte, whose patient developed an osteomyelitis and later pyemia, and one by Arnott, in which the spinous process of the second cervical vertebra was thrust by direct force between the arches into the cervical canal, and the patient died as a result of injury to the cord.

The treatment of these isolated fractures consists in rest and fixation with a light plaster jacket or with adhesive plaster strapping. The dislocated fragment should be replaced, although it may be difficult to retain

it in position. At a later stage massage may be employed to advantage and when, as happens occasionally, the displaced fragment continues in faulty position, and there is more or less persistent pain on motion, the detached fragment should be removed. As a rule, however, the course of treatment will not exceed four weeks.

Vertebral Arches.—The arches of the cervical vertebrae, particularly of the atlas and axis, are more susceptible to isolated fracture than those

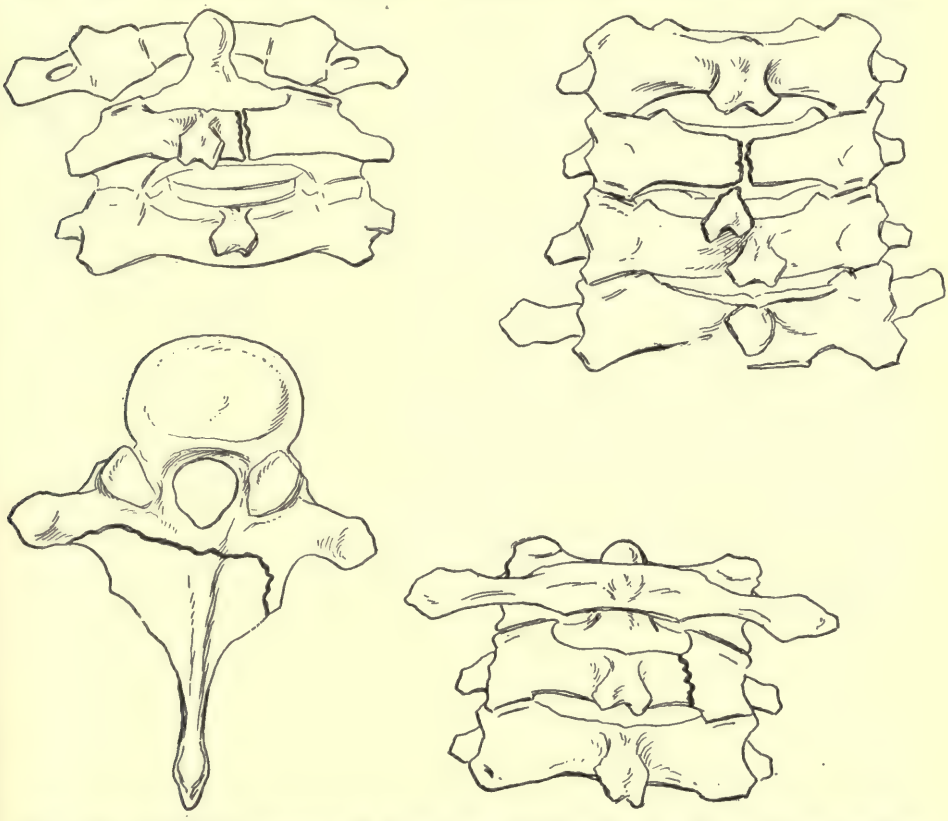

FIG. 175.—OUTLINE DRAWINGS OF FOUR CASES OF ISOLATED FRACTURE OF THE ARCHES OR LAMINAE.

of the thoracic and lumbar vertebrae, since the arches in the latter regions are firmer, thicker, and protected by a thick layer of muscles. Quetsch, however, has recently reported three cases of isolated fracture of the arches of the lumbar vertebrae. The fracture may be confined to one arch (Fig. 175), or several arches may be involved; it may be bilateral or unilateral, the latter, however, when involving but a single lamina being very rare. Delbet has reported a case in which there was an isolated fracture of the right lamina of the axis just at the union between the lamina and the articular process, causing a slight displacement of the

right articular process upon the corresponding vertebra. Picqué reported a similar case to the Société de Chirurgie in 1900, in which there was a fracture of the right lamina of the twelfth thoracic vertebra. In bilateral fractures there is often considerable displacement of the fragments, while in the unilateral fracture the displacement is ordinarily slight.

Isolated fractures of the arches of the vertebrae result almost invariably from direct violence, such as a severe blow on the back or neck, a fall on the back of the head and the like. More rarely an indirect force is responsible, particularly in the cervical region, where forced, backward flexion of the neck may be the cause. In these isolated fractures the cord and roots are exposed to injury since the cord lies in very close relation to the arches, and any violence severe enough to break the arch may force the displaced fragment into the canal and cause a contusion or crushing of the cord, or, more rarely, an injury to the roots.

The recognition of isolated fractures of the arches or laminae is not always easy of accomplishment. Suspicion is aroused by the character of the injury, the localized swelling and extravasation, by preternatural mobility, by the pain from pressure over the spinous processes, when fracture of other processes has been eliminated, by the sense of crepitus communicated to the finger on deep pressure and by the subjective sense of crepitus when the patient moves the head. The presence of a cord or root lesion would indicate a fracture of an arch rather than a spinous process, should there be any doubt as to which of the two processes was involved. Without these distinguishing features the differential diagnosis would be extremely difficult and could be determined with any certainty only by the roentgenogram. The importance of an accurate diagnosis and the recognition of cord involvement are borne out by the experience of Betz, whose patient, a fourteen-year-old girl, complained at first only of pain and trophic disturbances in the distribution of the left great occipital nerve. In consequence, upon continued pressure and cord involvement, the child developed convulsions, general paralysis, bulbar symptoms, and died three months after the accident. At autopsy pressure was found to be due to a fragment split off from the arch of the atlas which could have been readily removed by operation.

The treatment of isolated fractures of these arches is fixation or operation. Should there be any indication of cord or root involvement and little evidence of improvement within the first week, operation should be resorted to without any hesitation. Without cord lesions the treatment resolves itself into a matter of fixation with a suitable collar for a period of four weeks. By this time consolidation will be far enough advanced to prevent displacement and the fixation apparatus may be discarded.

Transverse Processes.—Since the employment of the x-ray as a diagnostic agent the incidence of isolated fractures of the transverse processes is very much greater than we were once wont to believe. In fact, up to

1908 there were recorded in literature, all told, only three cases, the first observation having been made by Ehrlich in 1908, but since that time the number has been increasing year by year. In the routine examination of 116 cases of injuries to the back, Ewald found 4 isolated fractures of the transverse processes and in a quite casual survey of the literature I have added 25 cases.

There has been some dispute as to the mechanism, but I think the evidence is now sufficiently strong to establish the claims of indirect violence as the most common cause. In fact, the transverse processes are so well protected by muscles that direct violence is probably an infrequent factor even when there may be a history of a fall or blow. The character of the injury may vary from one of a mild to one of a serious nature. The patient may be crushed between objects, may receive a violent blow on the back or strike an object in falling to the ground, as the case under my charge when the patient fell over the edge of a baby's crib. The muscular effort may be violent, as in an attempt to lift a heavy object, or may be comparatively trifling, as in the case of Brown and Dodd where, following a sudden jolt on horseback, the patient complained of moderate pain in his back and later there appeared some discoloration and tenderness to pressure. The pains in the back and legs increased in severity to such an extent that he had to abandon active exercise. The x-ray showed an unquestionable fracture of the transverse process of the fifth lumbar vertebra on both sides (Fig. 176). The application of a properly designed support was followed by very marked relief, and three and one-half months after fracture, when ossification had taken place, there was coincident relief from the pain in the back and legs to which the patient hitherto had been subject.

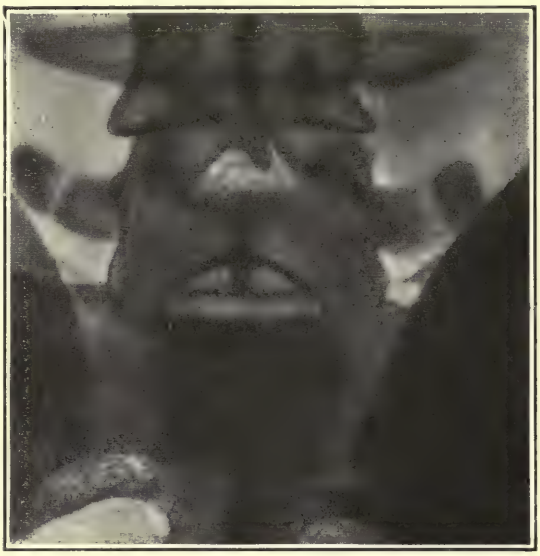

FIG. 176.—FRACTURE OF THE TRANSVERSE PROCESSES OF THE FIFTH LUMBAR VERTEBRA. (Brown and Dodd.)

The muscles, which play a part in the fracture of these processes, are the *psoas,* the *quadratus lumborum, erector trunci* and the *longissimus dorsi,* and their attachments readily explain the mechanism whereby muscular efforts, such as lifting or straining, may lead to fracture. Not only

one but several transverse processes may be fractured by indirect violence, such as in the case of Rhys, whose patient in attempting to lift a heavy object fractured the transverse processes of the second, third, fourth and fifth lumbar vertebrae (Fig. 177).

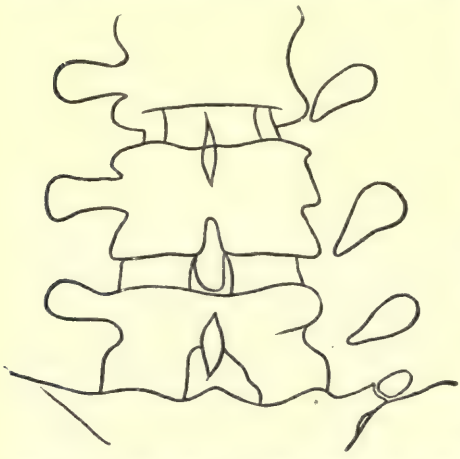

Fig. 177.—Fracture of the Right Transverse Process of the Second, Third, Fourth and Fifth Lumbar Vertebrae Due to Muscular Violence. (Rhys.)

With two exceptions (Ewald's and Taylor's cases) isolated fractures of the transverse processes affect only the lumbar vertebrae, possibly because the transverse processes of the lumbar vertebrae are larger and thinner than those of the thoracic or cervical region. They may be unilateral or bilateral, involve one or several processes, and are usually oblique from above downward and from within outward, involving the weakest part of the process, which may be called its neck, about the junction of the proximal and middle thirds. In multiple fractures the seat of fracture is successively further from the base beginning with the lowest process and going upward. The external fragment is usually displaced upward.

Tabular Statement of Incidence of Isolated Transverse Fractures

Single	23	1st Lumbar	7
Multiple	9	2nd "	9
Right side	16	3rd "	11
Left side	14	4th "	9
Bilateral	2	3rd Thoracic	1
Unilateral	30	7th Cervical	1

The subjective evidence of fracture of a transverse process is pain, sometimes moderate, sometimes violent. Referred to the seat of fracture, it may radiate to the lumbar and adjacent regions, to the coccyx, to the lower extremities, to the region supplied by the sciatic nerve, to the anterior abdominal wall, to the groin. In one instance (Payr and Hoffmann) pain was so severe as to embarrass respiration. Pain is aggravated by movements of the spinal column, flexion forward and laterally, rotation, going upstairs, flexing the thigh when in the recumbent position. If flexing one thigh does not elicit pain, flexing both thighs may. In picking up objects from the floor the patient assumes the same position as that of a patient with Potts' disease. Upon physical examination localized

tenderness may be elicited by pressure directly over the line of fracture. Crepitus has been elicited but occasionally; there may be a flattening of the surface if several processes be involved; there may be a moderate scoliosis with the convexity toward the sound side, due to involuntary muscular rigidity or to the assumption of this position by the patient as one of greatest ease. This temporary scoliosis may become permanent.

In some instances fractures of the transverse process may be attended with evidence of pressure upon the adjacent roots, as in Taylor's case where a fracture of the transverse process of the seventh cervical vertebra was attended with paralysis of the eighth cervical and first thoracic nerves (Klumpke's type of brachial palsy). The loose fragment was removed, and two months after the operation no improvement was noted other than the relief from the painful muscular cramps of which the patient had complained.

Without the x-ray the diagnosis of fracture of a transverse process can only be conjectural and before the days of the x-ray these fractures not only were overlooked but the symptoms were attributed to various conditions—lumbago, sprains, muscular and ligamentous injuries, rheumatism, arthritis deformans, tubercular spondylitis and traumatic neurasthenia. Retroperitoneal hematoma, complicating the injury, by pressure on the spinal nerves, was attended with pain referred to the lower abdomen and led Hoffmann to make a diagnosis of appendicitis. The diagnosis of fracture may be suspected when there is tenderness over the transverse process, pain on movements of the trunk and on deep inspiration, and can be confirmed only by the x-ray. With regard to the interpretation of the x-ray findings, vague thickening or deflections should be regarded as insufficient evidence of a preëxisting fracture; the x-ray diagnosis of fracture must be made solely upon the physical separation of the fragments at the time of fracture and upon displacement. Another important point, and one which should be borne in mind in medicolegal cases, is the occasional persistence of the epiphyseal line in the process of the first lumbar vertebra, which usually ossifies at the twenty-fifth year. A persistent epiphyseal line may be interpreted as a fracture.

As illustrating the ease with which the precise nature of the lesion may be overlooked, I may cite the case of a young woman whose physician brought her to the University Hospital (File No. 32123) because of persistent pain in the spine. In getting out of bed after a short illness the patient had fainted and fallen backward over the edge of a crib. The accident itself was not especially painful, but the pain persisted and for eight weeks the patient remained in bed. Suspecting some serious organic lesion of the spine the physician sought a consultation and in the course of our examination the x-ray revealed a fractured transverse process of the first lumbar vertebra on the right side. A plaster-of-Paris jacket was applied

and the patient was at once relieved and allowed to leave the Hospital.

Even when unrecognized and untreated these isolated fractures of the transverse processes consolidate and in course of time the symptoms subside. Pain and tenderness disappear and the freedom of motion in the vertebral column, no longer painful, is restored. The prognosis as to recovery of function, therefore, is, in the majority of instances, good. Exceptionally, however, because of the faulty posture assumed by the patient immediately after the injury a scoliosis may persist and in some cases there may be some restriction in the movement of flexion either forward or to the unaffected side. The hematoma, which forms at the site of the injury, may become infected, and the unattached transverse processes may undergo necrosis. Persistent pain after the fracture may be due to non-union on the one hand, or to callus on the other. The importance of routine roentgenological examination cannot be emphasized too strongly in injuries of the lumbar spine, and when a fracture is detected the patient should be kept at rest in bed for at least two weeks. If pain persist a light plaster-of-Paris jacket is applied and the patient allowed greater freedom. Under the influence of fixation and massage the subjective discomforts will gradually subside and in from four to six weeks the patient will be able to resume his occupation. When not seen until weeks or months after the accident the persistence of pain and disability may be regarded as an indication for the removal of an ununited fragment or of a mass of callus. Surgical interference has been resorted to a number of times with justifying results.

Kiliani operated upon a patient who was complaining of sharp stabbing pain in the right kidney region radiating across the back to the opposite side. Seven months before the patient had fallen a few feet, landing upon his back, but no importance was attached to this accident and, as a matter of fact, the painful symptoms made their appearance only three weeks prior to his examination. The x-ray revealed fracture of the transverse process of the first and second lumbar vertebrae, and it was not until the loose fragments were removed that the patient was relieved.

Articular Processes.—While fracture of the articular processes often occurs in combination with other fractures and fracture-dislocations, isolated fracture of the articular process is very rare. In going over the recent literature on fractures we have found but one such case, an isolated fracture of the right articular process of the fifth lumbar vertebra. An operation was performed by Hofmeister and the broken fragments of the articular process were removed. In Gurlt's classical monograph there is a photograph of a specimen showing a transverse, asymmetrical fracture of both articular processes of the axis (Fig. 178). The patient, a young man, 24 years of age, had fallen from a wagon, on his head, fracturing synchronously the occipital bone at the foramen magnum and the articular processes of the axis. He lived but a few hours.

The rarity of this type of isolated fracture is largely to be attributed to the fact that fracture of the articular processes at once exposes the vertebrae to dislocation. It may also be true that some cases have been overlooked in the past under the diagnosis of sprains, traumatic lumbago and the like; and with the more frequent roentgenological examination the number of cases will be increased.

Fracture of the articular process may be monolateral or bilateral and may be caused either by extreme overflexion or overextension; in the former instance, unusual to be sure, the tension on the capsular ligament finally tears away part of its bony attachment. There is more give and play to the capsular than to other ligaments and in the cervical region they permit greater amplitude of motion, while the articular processes are broad and flattened—conditions which do not predispose to fracture—so that tension fractures of the articular processes of the cervical spine are rare. In the thoracic spine the capsular ligament is shorter and fits more snugly about the joint and would be more promptly and positively influenced by hyperflexion. But even here the fracture is limited to the tearing off by the ligament of a spicule of bone from either the superior or inferior process. In the lumbar region the articular processes are of such dimensions that by tension alone they would not be likely to suffer fracture.

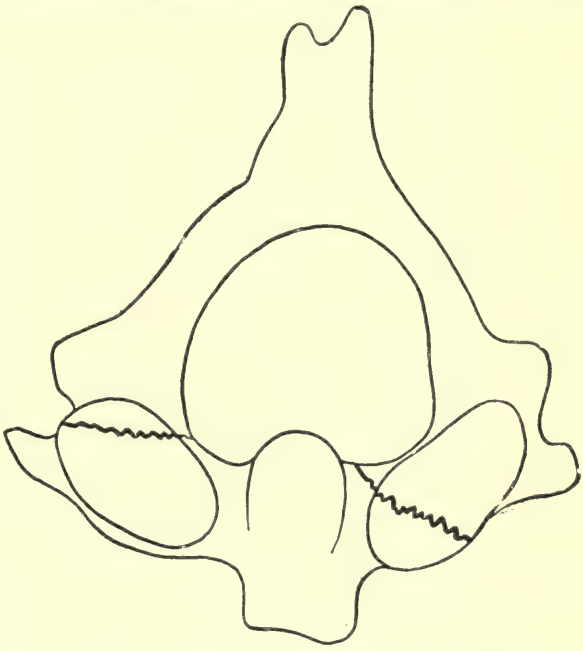

FIG. 178.—TRANSVERSE ASYMMETRICAL FRACTURE OF BOTH ARTICULAR PROCESSES OF THE AXIS.

The mechanism of fracture of the articular process must in most instances be one of indirect violence. At least, muscular action may be eliminated as a factor, as there are no muscles attached to the process and it would be difficult to conceive of a fracture of the transverse process due to direct violence. Theoretically, it is quite possible that the articular process may be fractured by tension of the capsular ligament in exaggerated movements of the spine. A movement which might cause a dislocation of the vertebra might readily cause a fracture of the articular

process if the capsular ligament remain intact. In the case of isolated fracture of the articular process of the fifth lumbar vertebra, the mechanism, according to Burk, was a combination of flexion and inclination. In the movement the anterior margin of the fifth lumbar vertebra was jammed against the anterior margin of the upper sacral vertebra.

Perhaps the most important feature of practical moment is the recognition of a definite lesion of the vertebra. Too frequently have the pains, often of long standing and at times disabling, been the result of these fractures. In these fractures there may be some slight lateral deformity, usually an inclination to the affected side, but this is by no means the rule. A symptom of considerable value is the involvement of a spinal nerve due to the fact that the intervertebral foramen at the point of fracture is greatly narrowed or altogether obliterated.

Vertebral Bodies.—The isolated or compression fractures of the vertebral bodies, quite unlike isolated fractures of the arches and processes, are caused almost exclusively by direct violence exerted along the axis of the vertebral column, combined usually with a certain amount of anterior flexion. They result most frequently from a fall on the feet, head or buttocks, or from the impact of a heavy object upon the back; it occasionally happens that a man carrying a heavy load on his back slips, and in the fall the jar of the load by compression fractures the vertebral bodies.

Fracture of the body of the vertebra, in cases in which there is no antecedent bone disease, is most likely to be in a plane, the sagittal axis of which inclines from posteriorly and above to anteriorly and below, and whose transverse axis is more or less horizontal, though in a minor proportion of cases the opposite inclination of the plane may be observed. The body becomes compressed and flattened out and, as a rule, its anterior portion is compressed more than the posterior and according to the direction of the fracturing force the damage may be more pronounced on one side than the other. A characteristic feature of isolated compression fracture is the absence of dislocation of the lateral articulation. Should this occur the resulting injury would be in most instances a total dislocation or total fracture-dislocation. In some instances but one body and in others several bodies may be involved; in the latter case the deformity is represented by a kyphosis. While there is a tendency for the superior fragment to be displaced forward and downward, in cases of extreme violence the vertebral column above the level of fracture may be displaced to one side or the other. However, since the fracturing force is directed downward in the axis of the spinal column there is, as a rule, no displacement. In process of compression there results often some comminution at the site of fracture and the pressure of the vertebra immediately above causes a fragmentation at the upper anterior edge of the body (anterior wedge fragments) (Fig. 179). Should the pressure be directed backward as well

as downward one or more fragments may be forced into the spinal canal and injure the cord or roots (posterior wedge fragments). In our series of cases of compression fracture there were associated injuries to the cord; in most instances, to be sure, the cord symptoms were but transitory. In

FIG. 179.—FRACTURE-DISLOCATION OF THE NINTH AND TENTH THORACIC VERTEBRAE, SHOWING GREAT COMMINUTION OF THE BODIES WITH DISPLACEMENT POSTERIORLY OF FRAGMENTS. (Allen.)

many cases when there is evidence of cord injury the possibility of hemorrhage, edema, contusion and compression must be considered, and if the contusion be due to a posterior wedge fragment the injury to the cord is usually irreparable, and the prognosis hopeless. (For further description of the pathological findings, *see* sections on concussion, contusion, hematomyelia and hematorachis.)

In 23 cases of compression fracture of the body, Kocher found 16 in the thoracic, 7 in the lumbar, but none in the cervical vertebrae. In-

deed, the lower thoracic and lumbar vertebrae, in spite of the depth and elasticity of their intervertebral disks, seem to be the place of predilection for this type of fracture—a fact which may be reasonably attributed to the larger dimensions and the relative immobility of these bodies. If a fracture follow a severe fall on the buttocks, and this is one of the commonest causes, it will almost invariably result in a fracture of the body of one of the lower thoracic or upper lumbar vertebrae. The limited degree of anterior flexion in the thoracicolumbar region is perhaps another factor accountable for the frequent occurrence of compression fracture in this region. In spite of the fact that a fall on the head is a comparatively common cause of vertebral injury, fracture of the vertebral bodies is unusual in the cervical region as in the lower portion of the column, since a force which would cause a fracture of the body in the lower thoracic region is more likely, because of the greater mobility of the cervical segment and of the thickness of the intervertebral disks, to result either in a sprain-dislocation or fracture-dislocation.

Isolated compression fractures of the vertebral bodies may be recognized by symptoms attributable to the skeletal injury, to the injury to the cord, membranes or roots, and the diagnosis may be invariably confirmed by the x-ray. Of the signs of skeletal injury mention should be made of localized pain, tenderness on pressure directly over the injured vertebra, the exaggeration of pain in bending forward or in attempting to lift heavy objects. The pain may be localized or may radiate to either side or may be comparable to the girdle sensation. Muscular rigidity and fixation of the affected portion of the spinal column are noticeable in many instances. Ludloff called attention to the fact that he has been able in many cases to obtain the sensation of crepitus by auscultation. The deformities resulting from compressed fractures as a rule are represented by a kyphosis, although occasionally one may see scoliosis and, in still rarer instances, a lordosis. Where there has been much compression of the vertebral bodies the skin of the upper abdomen, especially along the border of the ribs, may lie in heavy folds. As has already been said, injuries to the spinal cord, membranes and roots have been comparatively infrequent, and when they are present they are more apt to be transitory than of permanent duration.

The following is a brief record of two cases which occurred in the practice of Dr. H. R. Wharton:

Case 1.—C. S., *aet.* 20, was admitted to the Presbyterian Hospital, May 10, 1896. While riding a bicycle he was struck by a trolley car and rolled under the car. On admission he was found to have a lacerated wound of the scalp, general contusions of the body and limbs and marked projection of the spinous processes of the second and third lumbar vertebrae. There was no paralysis of the limbs, but anesthesia of the skin over the anterior region of thighs. The patient was kept at rest and in a few weeks a plaster-of-Paris jacket was applied and the patient allowed to sit up. He was discharged from the Hospital June 29th and continued

to wear the jacket for several months. When last examined the deformity in the lumbar region was still present and there was no evidence of cord injury.

Case 2.—B. H., *aet.* 28, admitted to Presbyterian Hospital, Jan. 17, 1910, jumped from the third story window and landed on her back upon a pile of snow. Upon admission she was suffering from shock and contusion of the back, and there was a marked deformity in the region of the second lumbar vertebra. There was no paralysis of the limbs but anesthesia of the skin over the anterior surface of the thighs. The roentgenogram showed a fracture of the body of the second lumbar vertebra. She was kept in bed and a plaster-of-Paris jacket was applied. She was discharged from the Hospital April 4, 1910, provided with a brace which she continued to wear for a year. When last examined, February, 1917, she was entirely well.

Of 47 cases in the collection of Quetsch 19 gave evidence of involvement of the cord and in the final analysis in sixteen the symptoms proved to be transitory, and in only three instances permanent. The cord symptoms may be the result of compression of an extradural hemorrhage, of edema, or hemorrhage directly into the cord itself or by laceration or puncture of the cord from the irregular surface of a displaced fragment. Root involvement from stretching, pressure or laceration is comparatively infrequent. A rather interesting example of this injury is the following case:

Fracture of the cervical vertebra with disturbance of motion and sensation confined to the forearms. The absence of motor, sensory or reflex disturbance in the lower extremities indicated a lesion of the cervical roots with escape of the cord.

The patient, a woman, *aet.* 47 (File No. 33634), was admitted to the University Hospital, November 4, 1916, twenty-four hours after the accident. At this time she had regained consciousness but complained of tenderness in the region of the cervical spine, numbness and weakness of both upper extremities. The roentgenogram showed fracture of the bodies of the third, fourth and fifth cervical vertebrae (Fig. 180). There was no impairment of motion or sensation in either lower extremity and no ankle clonus or Babinski reflex. The plantar reflexes were present, but the patellar reflexes absent. In the right upper extremity an area of hypesthesia was found extending from a point a little above the elbow on the extensor surface and a little below the elbow on the flexor surface to the tips of the fingers. The movements of the shoulder and wrist joint were unimpeded, but flexion and extension of the fingers and thumbs were impeded. The thumb could be adducted but not abducted. The elbow joint was ankylosed as a result of a lesion of long standing. There was a great deal of restriction of motion in the left upper extremity in that adduction and abduction of the shoulder joint were feebly performed and supination and pronation of the forearm were impaired. This restriction of motion, however, may have been due to a contusion of the shoulder joint because flexion and extension of the elbow joint were not affected.

The sensory disturbances in the left upper extremity corresponded somewhat to those of the right in that there was impairment of sensation from the level of the elbow joint to and including the fingers.

A fixation dressing was applied and the patient confined to bed for a period of two months, at which time a suitable brace was provided and the patient was allowed to get up.

In the interval between the accident and the date of the patient's discharge from the hospital—ten weeks—there was gradual partial restoration of motor function in that there was a firmer grip in each hand. The patient could flex and extend the fingers of both the right and left hand with greater facility than she could before. However, there remained a diminution of acuity for all forms of sensation in each forearm beginning at a level of about 2.5 cm. above the line of the elbow joint. This diminution of sensation was present on both the flexor and extensor

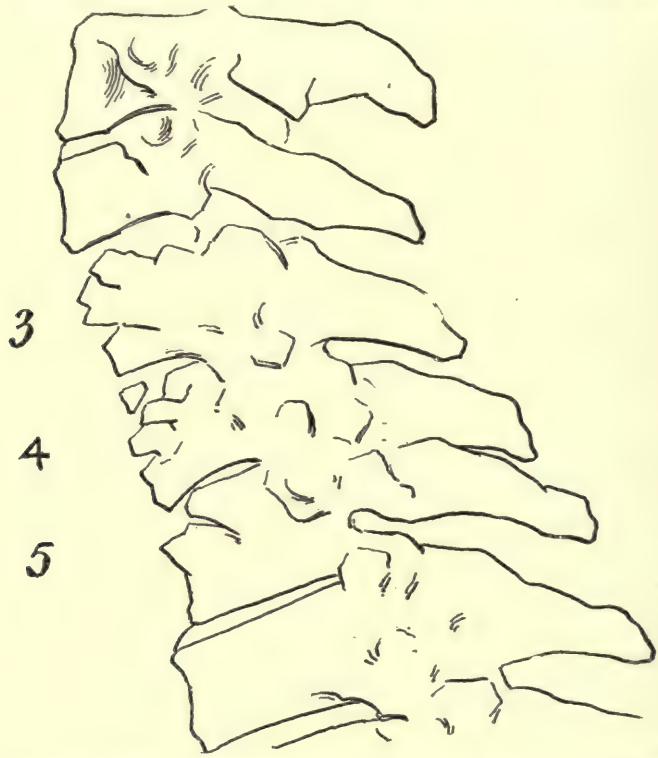

FIG. 180.—DRAWING FROM ROENTGENOGRAM (LATERAL VIEW) SHOWING COMPRESSION FRACTURE OF BODIES OF THE THIRD, FOURTH AND FIFTH CERVICAL VERTEBRAE. (University Hospital, File No. 33634.)

surfaces with the exception of the palms of the hands, where the patient readily distinguished between the sharp and the blunt points of the pin.

The interesting features in this case were, in the first place, the involvement of the bodies of the cervical vertebrae rather than of the thoracic or lumbar, and in the second place, the existence of so serious an injury, compression of three vertebral bodies, without involvement of the cord.

In a case of direct compression of the cord by a displaced fragment the injury to the cord is often serious. For this reason early exploratory operation should be considered quite justifiable. At all events the principles governing indications for operative treatment are precisely those which come up for consideration in fracture-dislocations (*vide* p. 429).

Under ordinary circumstances the treatment of compression fractures of vertebral bodies without displacement and without cord symptoms consists in rest and fixation with a plaster-of-Paris jacket. If after the expiration of from four to six weeks either pain or discomfort upon motion continue, these together with the muscular atrophy may be treated to advantage

FIG. 181.—APPROPRIATE FIXATION APPLIANCE IN THE AFTER-TREATMENT OF FRACTURES OF THE VERTEBRAE.

with massage and certain properly directed passive movements. However, until consolidation is complete the patient should continue to wear a gypsum or leather jacket (Fig. 181).

The prognosis as a rule is favorable. In most instances immobilization of the injured bodies results in consolidation at the line of fracture, and if the evidence of cord injury entirely disappear the patient will in some instances recover, though not all have been able to resume laborious work. In a series of 21 cases of compression fracture of the vertebrae (Quetsch) 14 were able to return to their former occupations; 7 cases were prevented from resuming their occupations because of continued disability, and of these 4 cases were more or less permanently disabled. However, even in spite of the persistence of a kyphosis the supporting function of the spine may be unusually good and the continuance of a light brace may add to the patient's comfort and increase his carrying capacity.

FRACTURE-DISLOCATIONS

Mechanism.—Trauma of the spine naturally falls under two subdivisions: trauma due to a forcible exaggeration of the normal amplitude of motion in the spinal column, indirect violence; and that which is the consequence of impact, direct violence. A combination of these types is possible. In the vast proportion of cases, trauma, in the sense of a sudden

lesion of the spine, is due to an exogenous force. There are, to be sure, a few cases on record where dislocations have occurred as the result of a muscular effort on the part of the patient, but such cases are rare, and in the last analysis, offer no element for consideration not obtaining in the more common type. For instance, Gurlt reported a case of fracture-dislocation involving the cervical vertebrae in which the patient caused the lesion by throwing back the head violently, in the act of diving into the water. But these are exceptions of rarity and involve no problem apart from injuries of the more usual etiology.

Indirect Violence.—The displacements caused by a forcible exaggeration of a normal motion may be classified, according to the direction of force causing the exaggeration, into overflexion, overextension, extreme lateral deviation and extreme elongation.

Overflexion.—Of all these mechanical causes overflexion is the most common. The history of such a case is usually that some heavy weight has suddenly been forced upon the patient in a manner to cause extreme flexion of the head on the chest or the thoracic on the lumbar vertebrae or possibly the lower lumbar on the sacrum. This is often the accident of the coal mine or other engineering operation where a large body of earth may bury a workman, folding him up like a jack-knife. The point of greatest resistance to such an injury is the thoracic spine, this being the case chiefly on account of the heavy ligamentous binding of the ribs. That flexion fracture-dislocations occur in this locality, of course, is undisputed, but they are not of frequent occurrence.

The cervical spine is the most frequent site of such injuries. Here the vertebral body has an anteroposterior diameter relatively and absolutely less than at any other level. This fact, of course, makes for the more perfect flexion and extension of the neck and so long as the articular processes maintain their ligamentous attachments, a superior vertebra will not slip forward on its inferior. But a great force applied, let us say, on the back of the head, forcing the head and neck into extreme flexion, will tend to tear loose one or both of the articular processes of the superior vertebra. With the tearing of both of these ligaments, the full force of flexion is exerted on the intervertebral disk with the result that there is a tearing of the disk and slipping forward of the body of the superior vertebra (Fig. 182). This usually carries with it a fragment of the anterosuperior lip of the vertebral body below. The mechanics of such a condition may not be clear until it is understood that the anteroinferior lip of the body of the superior or luxated vertebra acts in this condition as a fulcrum, and as such, brings enormous pressure to bear on the anterosuperior lip of the body on which it rests.

The thoracic spine offers less inducement to this type of injury than does the cervical. In the first place, the articular processes are more vertical and the external force is at once met by this protection. Of

course, should the force be overwhelming, then the articular surfaces of either the superior or inferior vertebra will give way and the displacement and damage will be extreme. But in the thoracic region we have, according to Allen, a ratio between sagittal and transverse diameters of the body of 353:323, the only section of the spinal column where the anteroposterior diameter of the body exceeds the transverse. The ratios of the cervical and lumbar regions are respectively 106:77 and 121:92. This is another cogent reason why, given the same amount of force, the anteroposterior flexion displacement does not obtain so easily in this region as above and below. We shall see later on, however, that the thoracic body ratio will the more easily tolerate a lateral displacement.

FIG. 182.—FRACTURE-DISLOCATION OF ONE OF THE UPPER THORACIC VERTEBRAE, SHOWING A SLIPPING FORWARD AND DOWNWARD OF THE SUPERIOR BODY. (Allen.)

The lumbar spine shows an analogous condition so far as the ratio couplet is concerned, to that seen in the cervical region, the transverse diameter being greater than the anteroposterior, and here again we find the frequent overflexion displacement. But it might be argued that the ratio simply showed a numerical relationship between transverse and sagittal diameters of the articulating surfaces of the body; that in reality the sagittal diameters of the lumbar vertebral bodies exceeded those of the thoracic. This is undoubtedly true, but it must be remembered that the leverage on the lumbar spine is much greater than that on the cervical. Force applied against the back of the head tending to hyperflex the head on the chest has no difficulty in accomplishing this flexion. Such a force working upon the upper thoracic spine would, on account of the relative immobility of the thoracic region, find its fulcrum in the lumbar spine and a long lever arm in the thoracic spine, a most admirable condition for the exhibition of force.

OVEREXTENSION.—In order to have as much displacement in cases of

forced overextension we must postulate the fracture of a spinous process. Nevertheless, displacement in overextension may obtain without such a fracture. As in the case of flexion so in extension displacements it were well to consider the cervical, thoracic and lumbar regions separately.

The cervical spine in overextension shows a great degree of curvature before the synchondroses are threatened. In the cadaver from C_1 to T_1 in extreme extension there will frequently be formed a quadrant of a circle without tearing of ligaments. Forced extension past this point tends more to fracture spinous processes and laminae than to a true slipping of one vertebra backward. Nevertheless, such displacement can take place, and when the extension is severe enough to separate widely the anteroinferior lip of the superior vertebral body from the anterosuperior lip of the vertebral body below there results a backward displacement in which the posterior tubercle of the transverse process of the superior vertebra rides backward and over the articular process of the inferior vertebra, reducing the spinal canal at times 100 per cent. In these extreme extensions of the cervical spine the bifid formations of the spinous processes tend to keep the column in this region in the sagittal plane unless there be a distinct torsion added to the external force. The amount of displacement of the superior on the inferior vertebra in the cervical region may amount to 1.0 cm.

The thoracic spine may well be divided into an upper and lower portion, the upper seven vertebrae possessing long, slanting spinous processes quite unfavorable to even a moderate amplitude of extension, the lower five having shorter processes and slightly greater possibilities of extension. The backward displacement in the upper thoracic spine may amount to from 0.5 to 0.75 cm. and the attenuation of the spinal canal to 50 per cent. As the space between the spinal cord and the spinal canal in this part of the column is the smallest, a 50 per cent decrease is a great embarrassment. The lower portion of the thoracic spine may present a displacement of 1.0 cm., but because of the change in the shape and size of the spinal canal its reduction does not exceed 50 per cent. In this region the hindrance to further backward displacement is the fact that in the superior vertebra, that part of the posterior aspect of the body which forms the anterior margin of the intervertebral foramen comes in contact with the superior articular process of the vertebra below. In order to have a further displacement it would be necessary to have a fracture of the superior articular process of the inferior vertebra—a condition which would not obtain without tremendous violence. As has been noted above, the costal articulations form an additional protection in the thoracic region to displacements as well as a hindrance to free motion.

The lumbar spine, on account of its straight spinous processes of great strength, offers but small amplitude for extension, particularly in the lower lumbar region. The thoracicolumbar region is less limited in motion,

the spinous processes being shorter. When the subject bends backward as far as possible, the greatest amplitude of extension involves T_{10}, T_{11}, T_{12} and L_1. In a traumatic extension in the lumbar region a greater displacement backward of the superior vertebra may obtain than in the thoracic spine, from 1.0 to 1.2 cm. being possible. The same check to further displacement exists here as in the thoracic spine, but it is not so effective, owing to the fact that the superior articular processes are set at a more obtuse angle and the intervertebral disks are very thick. Consequently in the lumbar spine there are found at times extensive displacements. The attenuation in the lumbar spinal canal in extension displacement may amount to 50 per cent in the upper lumbar, and 75 per cent in the lower lumbar region. In case of fracture of the articular processes this may be greatly increased.

Direct Violence.—Impact trauma of the spine must be viewed from the standpoint of several factors: the size, weight and the velocity of the impact body. The type of injury, both to the bony structure and spinal cord, is vastly different in the case of a bullet wound from what obtains when the body has been caught between the floor and shaft door of a slowly moving elevator. In the first case we have the impact body characterized by small size, light weight and high velocity, in the latter case by great size, heavy weight and slow velocity. In speaking here of weight, size and velocity, I use the terms in their mechanical sense.

Symptomatology.—It is necessary to consider the picture of fracture-dislocation from the standpoint of the spinal column as well as the spinal cord. As the symptom picture in regard to the cord lesion is the same in fracture-dislocation as in contusion and laceration of the spinal cord, we will consider the latter symptom-complex when dealing with contusion and laceration (*vide* p. 406). In addition to the skeletal lesion there may be a complete transverse or partial lesion of the spinal cord, or involvement of spinal nerve-roots at the level of inquiry. Then again the skeletal injury may exist without lesion of either cord or roots (Table VI). There may or may not be an obvious deformity; even in cases of severe fracture-dislocation a replacement, partial or complete, may obliterate all external signs. Usually in these cases the roentgenogram is of value, but even with this means, diagnosis during life is occasionally difficult. By far the greater number of visible deformities are of the nature of kyphosis, although lateral displacement is not uncommon. In the latter case, though the outward manifestations may be somewhat masked, yet a careful palpation of the spinous processes often discovers a malalignment. In the cervical region where the fracture-dislocation has involved one articular process and the bodies, leaving the other articular processes in fair position, the nature of the deformity is likely to be rotary as well as flexion in the sagittal plane. Where with fracture-dislocation there has been collapse or crumbling of the body of the vertebra—and this applies chiefly

TABLE V

NATURE OF INJURY IN 228 CASES OF FRACTURES AND 86 CASES OF FRACTURE-DISLOCATIONS AT VARIOUS LEVELS

	Fractures			Fracture-dislocations		
	Direct	Indirect	Not Stated	Direct	Indirect	Not Stated
Cervical	20	45	5	6	33	4
Thoracic	23	25	13	12	6	9
Thoracicolumbar	3	4	5	..	..	..
Lumbar	43	29	13	11	5	0

TABLE VI

AN ANALYSIS OF 228 CASES OF FRACTURES AND 86 CASES OF FRACTURE-DISLOCATIONS WITH RESPECT TO CORD OR ROOT INVOLVEMENT

	Fractures					Fracture-dislocations				
	Cervical	Thoracic	Thoracicolumbar	Lumbar	Total	Cervical	Thoracic	Thoracicolumbar	Lumbar	Total
Complete transverse lesion	28	23	4	6	61	14	14	0	4	32
Partial lesion	17	14	6	25	62	11	6	0	9	26
Root involvement	4	3	0	6	13	4	0	0	1	5
No involvement of cord or roots	20	16	2	47	85	14	4	0	2	20
Not stated	1	5	0	1	7	0	3	0	0	3
Total	70	61	12	85	228	43	27	0	16	86

to the last two thoracic and the lumbar vertebrae—there may be a depression of the spinous process of the involved vertebra and no great deviation in the spinal column either in the nature of a kyphosis or lateral deflection. Pain is an important symptom which is usually present with acute exacerbations when the patient is moved, with great tenderness when the injured area is palpated. The detection of crepitus by moving the trunk or neck is most injudicious whatever it may add to the diagnosis. There is great danger in such a manipulation leading to further displacement of the fractured and dislocated fragments and causing increased trauma to the spinal cord. The history of the accident usually makes

clear the likelihood of a fracture-dislocation. In the following history the trauma would certainly suggest the likelihood of a fracture-dislocation. Despite the trivial and transitory evidence of cord involvement, the roentgenological examination proved the severe character of the bone lesion.

Fracture-dislocation of the first and second lumbar vertebrae without evidence of a cord lesion, with the exception of some diminished sensation in the circumanal region and retention of urine for 48 *hours. Complete recovery.*

The patient, *aet.* 48 (File No. 33748), was admitted to the University Hospital December 22, 1916, four hours after an accident in which he had been caught between the top of an elevator cage and the ceiling. On examination after admission I found

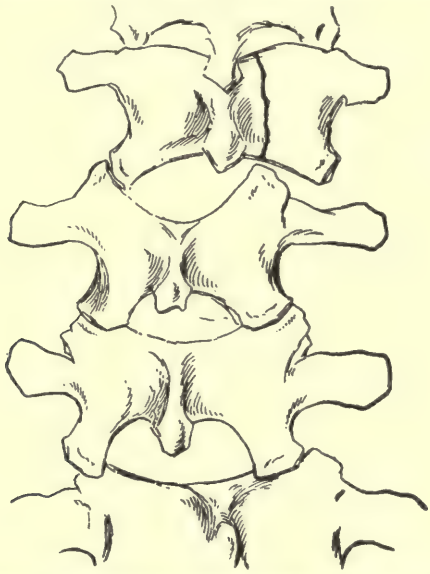

FIG. 183.—DRAWING FROM ROENTGENOGRAM, SHOWING A LATERAL DISPLACEMENT OF THE FIRST LUMBAR VERTEBRA AND A FRACTURE OF THE RIGHT LAMINA. (University Hospital, File No. 33748.)

a large area of contusion in the region of the lower thoracic and lumbar spine. Pressure upon it elicited great pain. Any attempt at movement of the back to one side or the other also elicited pain, but there was no evidence that could be detected on the preliminary physical examination either of fracture or dislocation. There was so much swelling and so much tenderness that the alignment of the spinous processes could not be determined, nor could crepitus be elicited. Physical examination showed that the patient was able to move both upper and lower extremities in all directions. There was no sensory disturbance of either upper or lower extremities; the knee jerks, however, could not be elicited nor could the right ankle jerk. Plantar stimulation was followed by withdrawal movements of the entire foot with dorsiflexion of the great toes. There was suggestion of diminution of tactile and pain sense in the circumanal region. The sphincters were active. The

patient's temperature, pulse and respirations were normal. He was quite conscious and able to describe the accident.

On the day of admission an x-ray picture was taken which showed a fracture-dislocation at the first and second lumbar vertebrae. The lateral view showed a crushing of the body of the second lumbar vertebra and a forward dislocation of the first for a distance of about a centimeter; and the anteroposterior view, a lateral displacement to the left of about one centimeter. There was a fracture on the right side of the lamina of the first lumbar vertebra (Fig. 183).

Apart from the fact that for the first few days the patient had to be catheterized there was no evidence of any lesion to the cord or cauda equina. A plaster-of-Paris jacket was applied for fixation and the patient kept in bed in the supine position for six weeks, at which time he was allowed to go out and, as soon as he was able to walk, to leave the Hospital.

The large majority of these cases have suffered an extreme violence, such as the caving in of a bank of earth upon a man in the stooping position. At times there has been a heavy blow on the back, such as occurred recently in a case at the University Hospital where a man had been struck by the end of a wagon tongue of a runaway team. The diagnosis is difficult only when there has been a reposition of fragments, in which case recourse must be had to the x-ray.

CONCUSSION OF THE SPINE [1]

Very frequently men disagree, not because their opinions are different on a given subject, but rather because they use a different terminology, the same terminology with a different application, or finally because their arguments are based on premises far from analogous. The subject of concussion of the spinal cord has offered a ground for scientific strife ever since the day when Erichsen, in 1875, first published his ideas concerning cases which he considered were the outcome of "molecular" disturbance of the spinal cord when the spine itself was not involved in any trauma. The work of Erichsen is interesting from an historical point of view, but his clinical observations were so faulty and his knowledge of neurology so inadequate that time is poorly spent in studying his cases or giving serious consideration to his conclusions. He may be thanked for starting a long and acrimonious medical struggle, and doubtless many

[1] The term "concussion," as applied to lesions of the brain and cord, is one which has had many interpretations, and in their defense as many dissertations have been written. As applied to traumatic lesions of the brain, the term "concussion" does not of necessity imply the existence of any demonstrable lesion, and in the same sense the author applies the term in the consideration of those injuries to the spine about to be discussed. It will be observed later on, however, that in gunshot wounds of the spine the term "concussion" will be applied to such lesions as are caused by explosions or by the passage of a bullet of high velocity in close proximity, and in this connection the term "concussion" may imply very grave structural changes in the cord, even to the point of complete disintegration. In the light of recent observations in the war zone it has become necessary to make this distinction between the concussion of civil and that of military origin.

a legal light in years to come will emulate the fraternity of the past generation in a deep sense of gratitude to one whose work has been the backbone of countless jury trials.

The question of prime importance is: Does such an entity as concussion of the spinal cord exist? Many will conclude, after reading laboriously through a number of the more recent works on the subject, that concussion is the "Mrs. Harris" of neurology. And right here we come to the crux of the whole discussion, the pathological *sine qua non.* It is evident to any clinician of experience that the spinal cord may be injured in cases of trauma without there being any lesion of the spine. This question has already been covered under traumatic hematomyelia and softening. Now, two schools of thought have obtained in this regard: The first holds that an impact or wrench of the spine may cause an abnormal condition in the spinal cord, not to be detected by histological means, and designated by that utterly vague and objectionable term, "molecular disturbance." The second faction believes that any case of trauma to the spinal column which later shows signs of organic disease of the spinal cord is in reality a case of traumatic hematomyelia or softening, although the hemorrhagic or softened foci may be so small that they escape detection except with careful microscopical search.

Concerning the theory of molecular disturbance, let us remember that, in the day of Erichsen, histological examination of the central nervous system was so in its infancy that no lesion, save the grossest, was ever detected. As histological technic advanced in accuracy and finesse we find that one condition after another had to be transferred from the list of functional to that of organic manifestations. Our present day accomplishments in histopathology, though encouraging, if viewed with a critical judgment, cannot fail to impress one with the realization that after all we see only comparatively gross changes. Hemorrhage, edema, sclerosis or softening are detected without difficulty. Tigrolysis of a nerve cell, if present in one of large, typical ganglion type, is rarely a subject for difference of opinion. But when we try to pass upon finer structures such as neurofibril formation or the tigroid substance of the many small and inconspicuous nerve cells, we come at once to the realm of speculation.

When we see degeneration by the Marchi method, we speak of some chemical change which has taken place in the medullary sheath of the nerve fiber which gives it a peculiar affinity for osmium tetroxid after previous treatment with the solution of potassium bichromate. But may we not imagine readily that we are here viewing a very extreme chemical change, and that only our lack of technical means keeps us from the realization that there are many gradations of nerve fiber abnormality existing prior to the advent of the osmic acid reaction? In this sphere of pure speculation all functional diseases or conditions may become potentially

organic. Now it is possible that some may have such a concept in regard to their hypothetical molecular disturbance, but let us bear in mind that lesions capable of causing paralyses, loss of reflexes and anesthesias have passed into the stage of the microscopically visible, with the exception of the condition we term spinal shock, and the latter is of temporary nature. Let us, therefore, dismiss molecular disturbance as a possibility in the consideration of the etiology of the case of so-called concussion of the spinal cord.

In discussing hematomyelia or softening as a possible factor in this condition, we are forced to ask the question: If this be the cause, why name the condition "concussion"? If there be any virtue in a name descriptive of the condition, the term "concussion" obviously fails, as it points rather to the cause than to the effect. Then again, let us suppose that the injury to the cord substance is due to a shock or blow transmitted through the blood or cerebrospinal fluid. In the case of the blood being the factor of transmission, we postulate an injury to the endothelial lining of the small vessels; where the cerebrospinal fluid is considered, the impact would be of more diffuse nature. But following this line of thought, it becomes difficult to determine just where one should draw the line between concussion and contusion and the more the mechanics of the situation are considered the more, it seems to me, is the question one of quantitative nature, the line purely arbitrary, the distinction without an essential difference.

We, therefore, hold to the opinion that where there is injury to the spinal column without a bony lesion but with subsequent alteration in the spinal cord it were well to class such a case as contusion and to eliminate the term "concussion" as applied to the spinal cord altogether. It nevertheless is incumbent on us to describe the clinical types so often spoken of as "concussion of the spine." On account of the frequency of this condition following accidents on the railroad it has been termed "railway spine" and has proven a perfect incubus to the law court.

Neurasthenic Type of "Railway Spine"

Etiology.—In a railway accident a man is often thrown forward out of his seat against the back of the seat or chair in front, or, in cases of rear end collision, is subjected to a violent impact along his entire spinal column, from lumbar region to lower cervical vertebrae, accompanied by the possible throwing back and extreme hyperextension of the cervical region. In case the line of force is oblique, he may be thrown into the aisle. Passing over without comment the superficial contusions and lacerations, there is frequently stretching and tearing of the ligaments of the spinal column which we may consider as sprain. This is invariably accompanied by pain of usually severe grade. Added to the above objective

injuries there is always a severe fright, and this must never be overlooked or belittled. The patient may be perfectly able to get up and walk to a place of safety after the accident, but the disturbance to his nervous system is quite apparent, and although objectively uninjured, he feels weak and dizzy and at times suffers from great emotional disturbance, weeping or laughing, possibly both together. Often, though helping to extricate his more unfortunate companions, he is greatly nauseated and vomits freely.

Now, there are four possibilities in the case just cited: (*a*) he may rapidly become perfectly well and show no ill effects from the accident; (*b*) he may demonstrate unmistakable signs of organic involvement of the spinal cord, which symptoms may increase in severity as time elapses, much like the cases of traumatic spinal *Spät-apoplexie* later mentioned (p. 388). These two eventualities are not germane to the subject of "railway spine" and, therefore, need not be further considered here. (*c*) He may become the subject of traumatic neurasthenia; and finally (*d*) he may suffer from traumatic hysteria. In our discussion of the symptomatology we shall consider the two latter sequelae.

Clinical Interpretation of "Railway Spine."—One is treading on dangerous ground in any attempt to discuss the etiology or predisposing factors in *traumatic neurasthenia* or *traumatic hysteria* and it is not our intention to launch an argument in favor of any particular school of thought in a book such as this. Nevertheless it is necessary to make a few observations concerning what we might term favorable soil for the development of neurasthenia or hysteria.

There is in every man the potential for a neurasthenia or hysteria. In speaking of neurasthenia, we shall be on the safe side if we give to the term its etymological meaning—absence of nerve power. But this very loose and unscientific definition needs much amplification in order to make it of avail. We may assume that a certain forceful reaction within a neuron is necessary in order to have that neuron carry out its particular function. Just as it is necessary to have the stimulus of a certain degree of intensity in order to set in action the nerve mechanism, so it is essential for the neuron to be in such a condition that the reaction to the stimulus is not only received but transmitted to the terminal fibers of the axis cylinder, there to be passed on to another neuron or else received in the end-station. Now, through any great shock, either psychic or physical, there may be elaborated in the body certain substances which have a deleterious action on the nerve mechanisms of cranial, spinal and autonomic systems. These substances are not necessarily abnormal in character; there may simply be an abnormal amount of a perfectly normal product. Such a concept has been elaborated by Cannon in his study of the physiology of the adrenal bodies in the state of fear.

So far as we know, the secretion of the adrenal body is only abnormal

in amount; there is no evidence that its composition is altered in conditions of shock, psychic or traumatic. There are other members of the endocrin system the physiology of which we know little. It may be possible that these organs under conditions of physical or mental stress may elaborate an excessive amount of normal or abnormal secretion, which may exert a most unfortunate effect on the neuron as a conducting mechanism. Of course this is speculative, but it is to some degree justified in the light of recent experiments in the physiology of the endocrin glands.

The following is a striking example of the influence of physical and psychic shock in the development of an hysterical syndrome.

Injury to the cervical spine. A blow upon the spine by a passing train produced a condition simulating a severe cord injury with almost complete loss of sensation and power in both lower extremities from which, in the course of five days, the patient fully recovered and shortly after walked out of the hospital.

The patient, *aet.* 26 (File No. 1070), was admitted to the University Hospital September 18, 1905, five hours after an accident in which he was struck in the middle of the back by a passing train. It was said that after the accident he could move his legs and had not lost the sense of touch. On his arrival at the hospital he appeared to be quite hysterical, throwing his head and arms about when any attempt was made to examine him. Pressure at any point over the body would elicit expressions of pain. An attempt was made to study the cutaneous sensibility, but the hysterical condition of the patient would not admit of any exact observations. While on admission he was able to lift his legs six inches from the bed, an examination four hours later revealed complete paralysis and loss of sensation in both lower extremities. The x-ray examination was negative. An examination by Dr. Spiller contained the following notes: The patient cannot move the right toes at all; can slightly flex the right foot and left toes, but cannot flex the left foot There is no movement of either limb or knee and only slight external rotation of the thigh. Sensation for touch and pain is entirely lost in the lower limbs and above up to a point about 3 cm. below the nipple. The cremasteric reflex is prompt on both sides, the patellar reflex is absent. There is continence of bowels and retention of urine.

Three days after the accident sensation had returned in both legs and over the abdomen, although somewhat impaired. The patient could flex both legs on the thigh and could extend the toes. A day later there was still further improvement in motion and sensation. The patient was able to turn himself in bed and voided urine voluntarily. On the fifth day after the injury the patient had complete return of both motion and sensation and was able to stand and to take a few steps unassisted. The case was regarded as one of grave hysteria.

We must now realize that the proper action of a muscle, either voluntary or involuntary, the normal action of all glands, somatic or splanchnic, the maintenance of a suitable blood pressure, the rhythm of the heart—all of these phenomena and a host of others are dependent on an orderly transmission of a correctly graduated nerve impulse. For instance, if there be a lack in the amount of nerve impulse traveling down the vagus,

we may expect certain very definite symptoms, such as increase in the pulse rate, lack of proper motility in the stomach, and other symptoms classed under diminished vagus action. Now the chief point to bear in mind is that there is not of necessity any lesion of the vagus or its centers. If the patient should happen to die and the most careful technic be used in the examination, there would not be found in such a case any deviation from the normal. In the same way let us suppose that the nerves of the lumbosacral plexus were in such a condition that, even provided they received their full stimulation from the upper motor neuron system, they were unable to transmit the adequate amount of energy to the end plates in the muscles. In such a condition the result would not be a paralysis, necessarily, but there would be a decided lack of power for continued effort. The patient would start to walk one-half of a mile and after covering one hundred yards would be forced to sit down and rest. *If this principle be applied to all the physical and chemical processes of the body the symptom-complex of neurasthenia may easily be postulated.*

We shall now describe a case of "railway spine," but before dealing with the accident we should better turn our attention to the previous history of the patient.

He is forty years of age and has always enjoyed good health. His temperament is of the nervous type and, following his previous illnesses, the periods of convalescence have always been marked by a lack of physical vigor, not justified by the amount or severity of the disease. A slight indiscretion in diet would cause him to have a mild gastro-intestinal attack followed by a period of a week or more during which he would be troubled with much abdominal distention and eructation of gas. These difficulties were never severe and he did not by any manner of means consider himself an invalid. In fact it took much probing into his past to piece together this picture. Nevertheless, it was apparent that for many years anything which would disturb the even tenor of his digestive canal would be followed by signs of somatic and splanchnic weakness altogether incommensurate with the cause.

At the age of forty he met with a railroad accident, being thrown violently forward by a head-on collision and then further disturbed by the turning over of the coach. In addition to a few inconspicuous, superficial lacerations and bruises, he suffered a violent blow on his spinal column at about the level of the first thoracic vertebra, as well as a bad torsion and hyperextension in the upper lumbar region. For a few minutes the pain was intense and he felt that he was powerless to extricate himself from his unfortunate position. In a few minutes, however, the pain in the upper thoracic region abated and with much difficulty and pain in the lumbar vertebrae, he was able to climb out of the car. Although always conscious of the acute pain in the lumbar spine, yet the excitement of the rescue work enabled him to render some assistance to

others. In about half an hour, however, the pain in his back had become so overpowering that he was no longer able to stand and was placed in an ambulance and removed to a hospital. A roentgenological examination failed to discover any skeletal lesion; there was no paralysis of either bladder or rectum and no anesthesia to any form of cutaneous stimulation. The reflexes seemed to be normal and plantar stimulation produced normal flexion. His prostration, for twenty-four hours following the accident, was extreme; his pulse was weak and rapid, his temperature slightly subnormal and a condition of profuse perspiration more or less constantly present. He complained of pain extending from his cervical region to his sacrum and a slight amount of movement in bed would cause him great distress which he located at the thoracicolumbar junction.

A diagnosis of sprain of the thoracicolumbar junction was made and for two weeks the patient was kept in bed with the spine immobilized as far as possible. At the end of this time it was deemed safe to allow him to spend several hours a day in a rolling chair. But it was quite evident that these periods had to be limited in time, otherwise he would have a return of pain throughout the spine with particular reference to the thoracicolumbar region. Three weeks after his admission he was sent home and there then followed a period of six weeks' rest under the care of his family physician. By the end of this time he had made much progress, was up and about the house and on bright days out of doors. Two months after the accident he was allowed to go to his office for a short time every day. Nevertheless, he did not feel altogether well. His appetite was poor. He was constipated, possibly for the first time in years. By three o'clock in the afternoon he was as tired as he usually would have been at eleven at night. A week went by with a certain amount of fluctuation in the symptoms and then, possibly owing to something he had eaten, he had an acute gastro-intestinal attack: nausea, vomiting, abdominal distress and diarrhea with great prostration and feeling of extreme malaise. Under treatment he recovered with fair celerity, but was dismayed to find that he was a querulous invalid. His physical stamina was gone; he could not walk a city square without feeling that he must sit down. The least little physical effort caused him to perspire profusely; he had vague pains about his body, which pains seemed to change their location from day to day, and in inclement weather there would be a return of his thoracicolumbar pain. General headache was frequent and reading quite intolerable.

We note that the symptoms in this history are chiefly of physical character. This selection has the object of demonstrating a neurasthenic picture and the reader is cautioned that a total absence of psychic symptoms would be a rare condition of affairs. It is an unfortunate fact that in dealing with the traumatic neuroses many writers have given the impression that the types—neurasthenia, hysteria and mixed—are rather sharply

defined. Such is not the case. The mixed form is the usual and the pure neurasthenic or hysteric variety a rarity.

We may now consider the symptoms of the neurasthenic type of "railway spine" under the headings of sensory, motor, reflex and visceral phenomena.

Sensory Symptoms.—In the neurasthenic type, subjective sensory phenomena are the rule and it may be stated that if there be an objective loss of sensation of any kind the picture is no longer a pure neurasthenic one. The pain of neurasthenic "railway spine" is both general and local. The general pains are rather vague in location, shifting from day to day, and deep seated rather than superficial. Often the patient, if intelligent, will describe the pain as one of extreme fatigue. This observation seems to be strengthened by the fact that it is frequently increased by exercise. Headache must take its place in the category of general pain. It is rarely a localized headache, although the patient may complain of more occipital than frontal distress.

In order that we may understand the physiology of the symptom of general pain, it were well to remember not only the possibility of a disturbed metabolism with the appearance in the circulating fluids of excessive amounts of normal and abnormal substances, but also let us bear in mind the possible action of these substances on the nerve fibers and cells as conducting mechanisms. If we admit the possibility of the posterior root ganglia of the lumbosacral plexus being subjected to some irritant circulating in the blood or in the cerebrospinal fluid, we must concede the logic of pain more or less severe in the lower extremities. By the term *local pain* I refer to the pain in the spinal column which the patient associates with the actual trauma. On palpation the spinal column will be found tender in one or more points, not infrequently throughout its entire extent. There will always be a doubt in the mind of the physician exactly how much of this is psychic and how much due to physical causes. At times this spinal pain proves a very intractable symptom and will be a great factor in influencing for the worse the patient's *morale*. Where the spinal pain is of physical origin it will often be noted that during convalescence the patient complains of exacerbations in stormy weather. A certain percentage of these latter cases will do particularly well on a combination of the iodids and salicylates.

Motor Symptoms.—The motor symptoms of a pure case of neurasthenic "railway spine" are of the exhaustion type. There is no true motor paralysis. The dynamometer may show by the first test a good grip, but the second test, if applied immediately, will show a marked falling off in the power, and in a minute, if the grip be constantly tested, there may be a loss of fifty to seventy-five per cent of the original strength. At times the spine is the chief locality showing loss of motor power. This may be rather deceptive in that where a condition of sprain obtains the patient is

not able to make the necessary effort, or he may relax in his effort as soon as he feels the painful sensation in the spinal column.

We may reckon *tremor* among the motor symptoms. At times the tremor is quite extensive, involving one or both extremities. Usually exhaustion greatly increases the tremor. Many patients notice that when they have walked too great a distance and sit down to rest they easily produce an ankle clonus. This, of course, is an exhibition of increased reflex activity, but in its cause is closely akin to tremor.

The deep reflexes in the neurasthenic "railway spine" are either normal or have a tendency to be increased. This increase may amount at times to almost a clonus, particularly if the part examined has been subjected to any exhausting exercise. Plantar stimulation never gives the Babinski phenomenon and spasticity is never present. As is often seen in the neuroses, there is more likelihood of the reflexes of the lower extremities being increased than those of the upper. The superficial reflexes remain unaltered.

Visceral Symptoms.—These symptoms divide naturally into vagotonic and sympatheticotonic signs. In the vagotonic variety we have slowing of the heart and increased muscular activity of the stomach and intestines together with an increase of secretory activity in the stomach. In the sympatheticotonic variety the cardiac rhythm is disturbed and the rate fast; there is an atonic condition in the stomach and intestines with an accompanying constipation.

The Hysterical Type of "Railway Spine"

We have discussed at some length the subject of the neurasthenic complex in railway spine; it now remains to deal with the hysterical variety, and it were well at this place to call attention, as in the previous condition, to the antecedent characteristics of the patient who is possibly predisposed to an hysterical affection.

Without discussing at length the several theories in regard to the genesis of hysteria, we shall note three radically different schools of thought. Babinski's teaching would lead us to consider hysteria as a condition of greatly increased suggestibility. Something, it may be a mental process within the patient, or it may be an episode in the patient's environment, suggests a condition, mental or physical, which the patient accepts as true and then adapts the body and mind to this new order. This description may be clarified by an example. An hysterically disposed woman is given a placebo by a physician, supposing it to be a strong stimulant to the nervous system. She experiences a great degree of vivacity and feeling of nervousness and there follows a night of almost complete insomnia, sleep coming only in the morning when the effect of the supposed drug has worn off. A man is in an accident and a number of his com-

panions are more or less seriously injured. Among others is a close friend whose spinal cord has been traumatized to the extent that he suffers a paraplegia. Although our patient may have only slight contusions and no involvement of the central nervous system, yet he rapidly loses strength in his lower limbs, and in twenty-four hours is quite paralyzed from his waist downward. In each of these cases there is a certain degree of similarity to an induced hypnotic state in which the first subject is given the suggestion that she has taken a strong drug the effect of which will be hyperstimulation or the second that he will become paralyzed in the lower limbs.

Those who hold to the view of suggestion as the chief factor in hysteria, explain the phenomenon on the hypothesis that the subconscious mind is the suggestible mind and that just so far as a person may lack the protective influence of a well-ordered waking consciousness, to such an extent is the subject open to the influence of suggestion. This view is not without much to commend it, as all can attest who have come into close contact with hysterical subjects.

Janet holds that on account of a cerebral insufficiency there is a retraction of consciousness, which retraction splits off, as it were, a certain part of the physical or mental individual. A patient's arm is paralyzed in such a case because it has been emancipated from the control of the waking consciousness. When you tell such a patient to raise the paralyzed arm, it is as though you were telling him to initiate voluntary movement in the body of another. So far as the genesis of the condition is concerned, it seems to me that the Janet hypothesis is quite unsatisfactory; one is at once met by the embarrassing questions: why and how?

Freud has elaborated a theory replete with the most interesting speculation. According to him, there is a certain censor action of the waking consciousness which does not permit painful thoughts to obtrude themselves. This school teaches that all painful thoughts are either reacted to by the emotion of shame, horror, disgust or the like, or else the censor action of the waking consciousness is strong enough to bury the episode in the subconscious without there being any such reaction. In the latter case, the episode is not lost irretrievably, but simply held from waking consciousness as long as the censor action is strong enough to protect the individual. According to Freud, painful episodes occur as far back in life as earliest childhood and of all episodes, mental and physical, a large proportion of the most painful are of a sexual nature. Now as one's mental equanimity depends upon the ability of the censor to keep these buried mental pictures from waking consciousness, it follows that whenever the censor is weakened by some intercurrent disease, physical or mental shock or some strong mental association, there is danger of the waking consciousness suffering from the contemplation of some episode of painful character. Therefore, in such times of stress there is likely to

be a compromise between the censor and the subconscious and the painful idea is converted into some bodily expression which in some way symbolizes the original episode. The exact explanation of how the symptom symbolizes the idea is reached through psychoanalysis. Freud's theory is that when, through psychoanalysis, the patient is brought face to face with the true psychic content of the symptom, he reacts to it by an adequate feeling of the particular emotion, disgust, shame or the like, and then, the cause being removed, and the conflict between censor and suppressed idea being obviated, the hysterical symptom disappears. Such is a brief and most incomplete statement of a theory in psychology which has set two continents by the ears and has been the origin of more acrimonious discussion than perhaps any other topic in the past generation. Had the protagonists been a trifle less *ex cathedra* in their assertion that the sexual was the one and only rôle in the drama, and had the antagonists been actuated more by a spirit of scientific consideration and less by vituperation, neurology and psychiatry would be the richer to-day. The chief point in the doctrine of Freud which bears on the question of "railway spine" is the fact that by the lowering of censor action, due to trauma and shock, the patient is well prepared for the exhibition of hysterical symptoms.

The history precedent to an attack of "railway spine" of hysterical type will in many cases show undoubted hysterical manifestations dating back perhaps many years. The absence of such a history should not, however, argue against such a diagnosis. We stated in the discussion of the neurasthenic type of "railway spine" that the pure neurasthenic syndrome was a rarity; it may also be said that the hysterical type with no admixture of neurasthenia would be even a greater rarity. For this reason it is unfortunate that we have to abide by the old classification of hysteria, neurasthenia and hysteroneurasthenia, in regard to "railway spine." The vast majority of the cases are of the latter type, in which, of course, either hysteria or neurasthenia may predominate. The following case might properly be included in this category.

Subsequent to a railway accident there was a general breakdown of the nervous system and pain referred to the spine without any evidence of a skeletal injury. Recovery after prolonged convalescence.

Immediately after a railroad accident a middle-aged woman was brought to the hospital with several scalp wounds and an area of contusion on the right side of the head, badly lacerated wounds of the right ear, contusions on the left arm, back and both sides of the chest. There was nothing of particular significance in the previous history other than that several months before she had had an operation for the removal of the coccyx, often indicating or determining a neurosis. For three weeks the patient was confined to bed and complained more or less constantly of pains about the body and along the spine but there was no evidence of any fracture. It was not possible to locate any point of greatest tenderness along

the vertebrae, since she complained of pain on pressure at various points and never twice in the same place. If she attempted to assume the upright position she at once complained of dizziness, quivered all over and seemed to lose entire control of herself. In the course of the examination when her legs were allowed to hang over the edge of the bed, there would begin a series of spasmodic contractions lasting for ten minutes or more. The reflexes of both upper and lower extremities were greatly exaggerated, but there was no evidence of either motor weakness or loss of sensation.

As week by week went by little change was noted in the patient's condition. She frequently complained of pain across the back, mostly in the lumbar region. Any effort on her part, as sitting up in bed or in a chair, was always followed by great fatigue. From time to time she had spells of crying and fits of depression. The application of a plaster-of-Paris jacket seemed to afford a certain amount of comfort but had little influence on the patient's nervous condition. Her invalidism continued for many months and not until after a protracted lawsuit was her nervous stability restored.

Symptoms.—The *motor* symptoms may show all degrees of paralysis, of both flaccid and spastic type. Parts not paralyzed may exhibit the rapid exhaustion described above and when such is the case the phenomenon may be either neurasthenic or hysterical. In fact there will be many symptoms the genesis of which will be in doubt.

The *reflexes* in the hysterical "railway spine" are likely to be preserved and normal, with the exception of a few dependent on sensory stimulation, like the pharyngeal, nasal and conjunctival which are frequently lost. Loss of plantar reflex with a preserved and normal knee jerk has been spoken of as a very frequent occurrence in hysteria. In spite of the normal condition of the reflexes a condition of stiffness simulating true spasticity is not infrequently seen. The ciliospinal reflex may be elicited even when the neck is the seat of an extensive and complete hysterical anesthesia.

The *sensory* symptoms are the most important in all cases of hysteria. All types of anesthesia are found, but frequently the distribution gives a clue to the real condition of affairs, as almost invariably the area of anesthesia does not correspond to any nerve or segment. Where the anesthesia affects the trunk the diagnosis is not so easy, as the location is often circular, about the thorax or upper abdomen, much as seen in an organic affection of the spinal cord. Where there is a hemi-anesthesia the line of limitation is not only much sharper than in organic cases but is also in an exact mesial plane. Various dissociations are met with which have no possible physiological explanation. It must be borne in mind that when we meet with an organic hemi-anesthesia, all forms of sensation on an entire side being affected, the lesion is likely to be thalamic and the anesthesia is most frequently not of very profound character. The normal innervation of the sound side extends slightly past the mid-line and there are likely to be other thalamic symptoms, such as hemi-anopsia, central pain, forced movements and the like.

Not only do we find hysterical anesthesias but also paresthesias and increased sensibility to the several forms of stimulation. At times the hysterically predisposed will give a history of having frequently had sharply defined areas of intense tenderness of the scalp, of such acute character that passing the comb through the hair is almost more than the subject can bear.

The special senses are particularly open to alteration in hysteria from any cause and in this regard that from "railway spine" is no exception. Hysterical anosmia is not infrequent, and the same may be said of perversions of olfaction, parosmia. Then we find a condition analogous to the paresthesias in the olfactory function: the patient detects strong odors, pleasant or the reverse, when no olfactory stimulation can be present. In regard to the ocular symptoms in hysteria, we have limitation in the fields, usually of a concentric nature, although at times variations occur, such as a concentric diminution in one primary color with no corresponding effect in the other colors. Amblyopia is frequently observed and the literature of ophthalmology is replete with methods of differentiation between hysterical and true amblyopia. Hemi-anopsia is of such rare occurrence that its presence would be a strong argument in favor of an organic lesion. Alterations in hearing are of common occurrence in hysteria and take the form of moderate increase or decrease in auditory acuity. Complete hysterical deafness is a rarity. The sense of taste is affected in the same manner as we have noted in regard to the sense of smell.

There are a few observations which it were well to bear in mind in making an estimate of the condition of the hysterical subject. In the first place the symptoms of hysteria thrive on observation. Some of the best results are attained by no other means than complete isolation of the patient and a seeming indifference on the part of the attending physician. This treatment is partially possible in a hospital ward by the use of screens. Be careful not to look on the hysteric as a malingerer. He may be such, to be sure, but the chances are that in the vast majority of cases he is honest. It is well not to use the term *imagine* to the patient; it often gives offense, especially to the less educated, who attach to it a significance either of rascality or weak mindedness.

Effect of Litigation.—What I shall say on the score of the development and continuance of symptoms in the face of an approaching law suit for damages will largely, I fear, counteract my statement in the preceding paragraph concerning malingering. And yet it is a truth which cannot be denied by any who have had much experience with these cases, that although the patient has a high ethical sense, the lawsuit adds fuel to the fire, keeping the symptoms up to highwater mark. As soon as the litigation is concluded a general improvement is noted in the vast majority of cases. The patient suffering from a complete paralysis of both lower limbs soon mends sufficiently to take to crutches; from these to a

cane is a short step, and the prognosis as to complete restoration is favorable. This question is an ominous and threatening one to-day with state after state aiding to the best of its ability the damage suit by its attitude toward the liability of employers. But so far as the curative effect of a successful suit is concerned, it is a veritable Bethesda.

Without taking up a mixed type of "railway spine" in a separate discussion I have endeavored to show that almost all cases are mixtures of neurasthenic and hysteric syndromes. It only remains to call attention to a common mental picture in "railway spine" which is from the psychological standpoint the analogue of neurasthenia and may well be termed *psychasthenia.* There is a weakness of initiative, a rapid exhaustion of the power to concentrate and at times a perversion of mental process which may lead the uninitiated to make the diagnosis of a psychosis. Imperative ideas, recurring painful mental pictures and a lack of feeling of reality are often found.

Treatment.—The treatment of cases of "railway spine" without organic involvement is in no sense different from the treatment of neurasthenia and hysteria from other causes. Isolation, rest in bed, suggestive means such as massage, electricity and hydrotherapy, and psychotherapeutic measures are all valuable.

HEMATORACHIS

Etiology and Symptoms.—Hemorrhage within the spinal canal of extramedullary origin may be either epidural or intradural. The former variety is the more common and is usually caused by the rupture of one or more of the epidural vessels—chiefly the venous plexuses. At times the amount of blood without the dura may attain considerable extent and cause pressure symptoms. Blood in the spinal subarachnoidal space is frequently secondary to hemorrhage in the cranial cavity. When this is the case, we may find on *postmortem* examination the cord completely surrounded by a mixture of blood and cerebrospinal fluid. But in such a case the cerebral symptoms would be likely to mask those due to irritation of the spinal cord, thereby rendering the diagnosis difficult or impossible. At times there may be hemorrhage between the dura and the pia-arachnoid, usually secondary to trauma of the spine. In this eventuality the patient may give evidence of spinal root irritation: stiffness of the neck and truncal spine, lancinating pains in the extremities and girdles of pain and hyperesthesia about the trunk. In subarachnoidal hemorrhage, Lewandowsky makes the point that if the origin of the hemorrhage be located in a walled-off space we may have a true compression of the spinal cord. This condition would be not unlike a circumscribed serous meningitis, and although the diagnosis would be most questionable, yet in case of operative interfer-

ence the true condition of affairs would be discovered and corrected. In cases dead of tetanus, eclampsia and like spasmodic conditions, *post-mortem* examination has frequently revealed a condition of epidural hemorrhage. This may be agonal in origin, as von Leyden has pointed out. Although compression and irritation symptoms are frequently present in the subdural and subarachnoidal hemorrhages, yet it must be noted that epidural hemorrhage rarely leads to either of these symptom pictures. Hematorachis may be also due to the rupture of an aneurism into the spinal canal. As a contributory factor may be mentioned obstructive heart, lung or liver disease. Risien Russell says that he has seen extradural spinal hemorrhage in the lower cervical and upper thoracic region associated with an external purulent meningitis. Cases have also been reported in which, due to a difficult breech delivery, there has been an epiphyseal separation in a vertebra, tearing of the anterior ligament and consequent hematorachis. Intracranial hemorrhage from any cause may lead to a passage of blood through the foramen magnum into the spinal canal.

The symptoms of hematorachis are chiefly due to anterior and posterior root irritation. There may be sudden pain in the back, of severe grade, corresponding to the part of the canal involved. This pain is not increased by pressure but may be by movement of the trunk. There are sharp, radiating pains in the distribution of the posterior nerve-roots of the segments involved. These pains are due to irritation of the posterior roots either in the canal or in the intervertebral foramina. There may also be from the same cause, hyperesthesia, hyperalgesia and various forms of paresthesias. The irritation of the anterior nerve-roots may lead to clonic jerking and stiffness of the limbs. If there be a motor weakness or paralysis, it may be due to compression of the cord, in which case it is of upper motor neuron type, or it may be caused by involvement of the anterior roots, in which event the paralysis is of lower motor neuron variety. Hemorrhage in the cervical region may cause a brachial diplegia. The most serious symptom picture presents when the hemorrhage originates in the neighborhood of the cauda equina. The pain under these circumstances is very severe in the distribution of the sensory elements of the cauda, and the vesical and rectal mechanisms are disturbed or altogether destroyed. At times, however, as in a case of Lewandowsky, even in the event of cauda involvement, absorption takes place and partial or complete restoration of function ensues.

Diagnosis.—The diagnosis of these cases, as in hematomyelia associated with trauma, depends largely on the rapid development of the symptom picture following injury. In hematorachis pain is a prominent sign, whereas in hematomyelia it is of minor character. In hematorachis the disturbance of sensation may be of all types, while in hematomyelia there is usually demonstrable a dissociation of sensibility. Lumbar puncture

usually detects the hemorrhage in hematorachis, but in hematomyelia the fluid is clear. In performing the lumbar puncture for diagnostic purpose in these cases one should be careful not to mistake the blood which may be due to a punctured blood vessel for blood in the cerebrospinal fluid. Usually in the former case after a few seconds the fluid becomes clear. If there be any doubt it would be well to centrifugate the fluid when, if the blood be from a punctured blood vessel, the supernatant fluid will be clear and colorless, while in the latter case the supernatant fluid will be straw colored or pinkish.

HEMATOMYELIA

It should be realized that it is not necessary to have a lesion of the spinal column in order to have hemorrhage within the substance of the cord. There are numerous cases, both clinical and experimental, which prove beyond doubt that impact to the spinal column without fracture of the vertebrae is capable of producing hemorrhage within the cord substance. The mechanical explanation may be sought in the fact that a shock is transmitted to an incompressible column of fluid contained in delicate elastic tubes which, particularly in the gray matter of the spinal cord, receive but meager support from the surrounding tissue.

The collection of blood in a case of hematomyelia may vary in size from a small group of erythrocytes, visible only through a microscope, to a large cavity full of blood taking up over half the transverse area of the cord. The vertical extent of hemorrhage within the cord substance may be confined to a part of one segment or may be found in continuity through many segments. In microscopical examination of these cases it becomes very evident that the supporting strength of the gray matter is much inferior to that of the white, as often the hemorrhagic area seems to be confined to the gray matter. Again, when both gray and white matter are involved by hemorrhage, the degree of involvement in the gray matter predominates. In experimental impact to the spinal cord Allen frequently found that whereas there might be numerous discrete, miliary hemorrhages in the white matter, the entire gray matter would be practically a hemorrhagic mass. One is often surprised in making a cross section of the spinal cord at a *postmortem* examination to find a hemorrhage running in continuity through many segments. Let us suppose, for instance, that our first section is through the third lumbar segment; at this level we may find a small hemorrhage the size of the head of a pin occupying the posterior horn on the left. In the segment immediately above, the hemorrhagic area is several times as large and has begun to invade the anterior or posterior gray commissure. Two or three segments higher the bulk of the hemorrhage is on the right, and possibly still higher may occupy both sides of the cord and even invade the white matter. This condition

has been most graphically depicted by Bailey. At times, serial sections through hemorrhagic segments will demonstrate that there are several independent collections of blood in the substance of the cord. Though our chief consideration is with traumatic hematomyelia, nevertheless, we must not forget that in cases of softening of the spinal cord from other causes than trauma, such, for instance, as syphilitic myelitis, the supporting power of the cord substance may be greatly weakened as may also be the walls of the blood vessels themselves, so that a very little exertion or even no exertion at all may usher in the spinal apoplexy. Then again there is a condition analogous to delayed apoplexy (*Spät-apoplexie*) in the brain. The history of such a case may be that the patient has been the recipient of a blow on the spine, severe though not necessarily disabling. In several days he may be thoroughly recovered and may be leading his everyday life. In a week or two there may be a spontaneous apoplexy in the substance of the cord. The pathology of this condition is supposedly like that of the more frequent cerebral variety: a softening about the blood vessels due primarily to shock to the column of blood in the arteries, causing injury to the endothelial lining.

Depending on the amount of the hemorrhage, the following appearance may be presented on cross section of the spinal cord years after the injury: Where the hemorrhage has been very slight there may be simply a neuroglial condensation without even a blood pigment staining; then again in hemorrhages of severer grade there may be the same scar formation with a deposition of blood pigment staining the focus an orange color; in those cases where there has been what might be considered a blood cyst there will be a neuroglial condensation forming the wall, which will surely be pigmented, while within the cavity there may be a straw-colored fluid.

According to Doerr's statistics, the age of greatest incidence for hematomyelia is the third decennary. Naturally, males are more prone to this condition than are females, this obviously depending upon the fact that men are ever more open to trauma than are women. In cases of suffocation a condition of multiple miliary hematomyelic foci is frequently found which may be due to sudden increase in blood pressure combined with possible excessive muscular exertion.

Symptoms.—As might be imagined, the most varied symptom picture may be presented in cases of hematomyelia. If the hemorrhage be confined to the gray matter of the cord, there is likelihood that the syringomyelic type of dissociation of sensibility may obtain. In such a case there is little if any interference with tactile sensibility, but much loss of pain and temperature sense in cutaneous surfaces corresponding to the segments involved in the hemorrhagic process (Fig. 184). If the hemorrhage extend into a lateral column, thereby affecting a cross pyramidal tract, it may cause a syndrome not unlike the Brown-Séquard picture. But the chances are that the areas of analgesia and thermo-anesthesia will

be vague in outline and that certain cutaneous areas will escape—a condition quite impossible were there hemisection of the cord. It is well to remember that often hemorrhage into the substance of the cord may be progressive in type. For instance, a man may receive a severe impact to the spinal column and yet be able to get up on his feet and walk for a time. However, in an hour, possibly, weakness of one or both legs may develop, and later on, if the hemorrhage increase, this becomes a paralysis

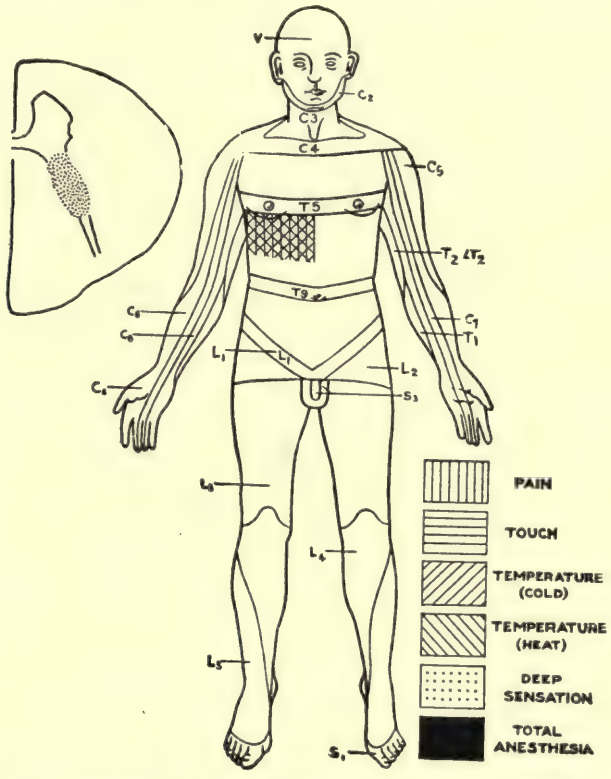

FIG. 184.—A HEMORRHAGE OF THE POSTERIOR HORN ON THE RIGHT, EXTENDING THROUGH T_6, T_7 and T_8.

Note that the cutaneous areas below T_8 are normal in sensation and compare with the diagram of the Brown-Séquard syndrome (Fig. 202).

of upper or lower motor neuron type, according to the level involved; a careful sensory examination will then demonstrate a cutaneous area of analgesia and thermo-anesthesia. What has happened is that there has been a rupture of a small blood vessel and gradually the blood has collected about the damaged focus until, either by pressure or extension, it has caused the equivalent of a transverse lesion.

It may be stated that when an appreciable time elapses between the spinal trauma and the spinal cord symptoms, the question of hematomyelia

must be carefully considered; and when in a case of slight contusion of the spinal cord with but a moderate symptom picture a sudden exacerbation of cord symptoms takes place, we must bear in mind the likelihood of either an extension of a primary hemorrhagic focus or a secondary hemorrhage in a softened area. The following case was admitted to my service in the University Hospital in August, 1902:

A man, *aet.* 23, while diving, thirteen months prior to admission, was thrown from the spring-board in such a way that his spinal column was hyperextended to such a degree that the lower limbs almost touched his head. Immediately he experienced sharp, shooting pains through his back and abdomen. He rested for awhile and then continued swimming and diving. Six hours later the pain became more severe when he made any motion, but he had no pain while standing still or sitting. Several hours later weakness appeared in his lower limbs and walking became extremely difficult and painful. About this time he lost the power of voiding his urine. Immediately after the accident he lost control of his bowels. In twenty-four hours after the accident he was unable to walk and was voiding urine unconsciously. At the time of his admission he knew whenever micturition or defecation occurred. An examination nine days after admission showed almost complete paralysis of the lower limbs, the flexor muscles of the thighs alone retaining any power. Both lower limbs were extremely spastic and were held in a position of flexion, but could be extended by the examiner. The right knee jerk was exaggerated; the left knee jerk could not be obtained, owing, most likely, to the spasticity. Ankle clonus was pronounced on both sides. Diminution of sensation was not marked in the lower limbs, but sensations of pain and touch were possibly not quite so acute as in the upper extremities.

This case illustrates most aptly the *late* hematomyelia. The pains immediately following the severe wrench to his spinal column may be accounted for in any one of several ways: (*a*) a tearing or stretching of the ligaments of the vertebrae; (*b*) a tearing, stretching or contusion of the posterior roots; (*c*) a small hemorrhagic focus in the gray matter of the spinal cord, later the seat of a more extensive process.

In stating the **prognosis** of hematomyelia, let it be understood we refer to an uncomplicated condition, and not to the case presenting a severe contusion or laceration of the spinal cord. In the uncomplicated case the prognosis as to life is good. In those cases where the hemorrhage is large and located high up in the cervical region there may be embarrassing respiratory symptoms due to diaphragmatic paralysis, and in such cases pneumonia has proved a fatal complication. Also in cases involving the lumbosacral enlargement, with bladder and rectal disturbance, decubitus may give much concern, leading eventually to septic condition and death. But the usual course for these cases to follow is one of gradual improvement with, at times, a surprisingly small amount of residual paralysis. Concerning the fate of the blood which is poured out into the cord substance there has been expression of several opinions. According to Lewandowsky, resorption of the blood had largely taken place after ten

months in a case of Mingazzini's, and after six weeks in a case reported by Kocher. It is likely that the time for resorption is extremely variable.

In cases of hematomyelia uncomplicated by contusion the type of paralysis is more likely to be lower than upper motor neuron on account of the fact that the damage is chiefly confined to the gray matter; in fact, it may be with extreme difficulty that we are able to differentiate in old, recovered cases between hematomyelia and syringomyelia, on the one hand, and the residual picture of anterior poliomyelitis and progressive spinal muscular atrophy on the other. Of course, this difficulty obtains only where the cervical or lumbosacral enlargement is involved. In hematomyelia of the thoracic cord the motor paralyses are not detectable unless the amount of hemorrhage be such that either through extension or direct involvement, the lateral columns are affected, in which case the picture of upper motor neuron paralysis of the lower limbs presents. Where the extent of hemorrhage in the cervical enlargement is very great, one may have not only the lower motor neuron paralysis affecting muscles supplied by the brachial plexus, but also the upper motor neuron paralysis of the lower limbs through pressure or direct involvement of the lateral columns.

Treatment.—The only possibilities in treatment relate to the hygienic measures directed toward prevention of decubitus and the usual precautions directed toward the prevention of cystitis. Where intractable spasticity follows lateral column involvement, attention may be directed to the possibility of relief from posterior root section. Massage and electricity may be used with the hope that the physical condition of the muscles may be conserved to the utmost, but little hope can be held out from these means.

CONTUSION OF THE SPINAL CORD

In contusion of the spinal cord there has been an impact without a physical solution in continuity. This subject has been investigated from the experimental point of view by Allen, who found that the severity of the permanent symptoms and the prognosis as to life depend upon the severity of impact. Small impacts sufficient to cause complete paralysis, motor and sensory, with initial loss of all reflex activity below the level of the injury, may not be inconsonant with complete recovery. Unfortunately, it is impossible to say definitely that we are dealing with such an impact and not with a hopeless condition. In the vast majority of cases contusion of the spinal cord forms the most important factor in fracture or dislocation of the spinal column. However, contusion of the cord is possible without fracture or dislocation, as illustrated in the following case:

Contusion of the cord without fracture of the spine and without motor or sensory disturbances, with the exception of rectal and vesical incontinence. Recovery from rectal incontinence. No operation.

The patient, a man, *aet.* 38 (File No. 28649), fell 35 feet to the ground and immediately after the accident he was unable to walk. On admission to the University Hospital on the day of the injury, October 12, 1914, an examination revealed some tenderness in the lumbosacral region but no evidence of deformity, crepitus or preternatural mobility. The roentgenogram found no fracture of the spine, but a fracture of the ramus of the pubis on the left side. There were no motor or sensory disturbances of any of the extremities. The biceps, triceps and tendon reflexes were normal and equal; the patellar tendon reflexes were equal but sluggish; there was no Babinski phenomenon and no ankle clonus. There were complete retention of urine and fecal incontinence. An indwelling catheter was employed until November 3rd, when signs of infection suggested the propriety of a suprapubic cystotomy. The patient's condition remained unchanged, with the exception of the fact that the anal sphincter had regained control, for the time he remained in the hospital, and upon his discharge, April 2, 1915, almost six months after the injury, he was able to walk around and had recovered with the exception of the vesical incontinence which still remained.

The mechanics of vertebral displacement has already been considered; now we may well turn our attention to the injury that such bony displacement is likely to inflict upon the spinal cord. There are two possibilities in fracture-dislocation cases, either one capable of causing irreparable damage to the cord. The first possibility is that the fractured or luxated vertebrae remain luxated and continue to press on the cord. This condition is less common than might be supposed, but if present is, of course, the most unfortunate type of bony injury. On account of the relative narrowness of the lumen of the spinal canal in the thoracic region there is more likelihood of a continued pressure from displacement occurring here than in the cervical or lumbar region. To this type of bone injury we may add that condition in which, through direct violence, the laminae have been fractured and driven in against the spinal cord. The second possibility in contusion of the cord is the case in which there has been displacement with impingement on the spinal cord by the vertebrae in question, the muscles and ligaments subsequently replacing the vertebrae sufficiently to restore the lumen of the canal.

In either of the above cases the cord has been to some extent crushed, and if laceration fail, we speak of it as contusion. Usually the lesion extends fairly symmetrically across the cord and we have the symptom-complex of transverse lesion. At times, however, the luxation or fracture of the spine has chiefly involved one articular process with a consequent torsion displacement causing a contusion of one side of the cord only. In such a case we may expect a Brown-Séquard type of paralysis and sensory disturbance. At times we may see cases which have suffered a trauma to the spine and present the picture of complete transverse lesion of the cord.

The roentgenogram fails to detect any fracture and it is likely that dislocation has momentarily taken place with an almost immediate replacement of the vertebrae concerned. On account of the well-defined level of anesthesia we may decide to perform a laminectomy, and on exposing the spinal cord are surprised to note that there is no diminution in the lumen of the spinal canal and but little visible alteration in the spinal cord. Nevertheless, the cord has been contused and though the pressure has been at once relieved yet a damage has been suffered, the effects of which may be fatal. Even after we have opened the spinal canal and dura mater and have had a good view of the injured segment, we should never give a positive prognosis concerning a contusion of the spinal cord. Some of the most innocent looking cases prove the most intractable.

The following is a case of contusion of the cord caused by a spontaneous reduction of a spinal dislocation in which the injury to the spinal cord was fatal, reported by Allen as follows:

> A young student while wrestling in the gymnasium suddenly felt something "give way" in his neck and immediately suffered complete paralysis in the lower limbs. The grasp in each hand was weak, but motion at the shoulder girdle was preserved. Examination for sensory change pointed to a lesion of the eighth cervical segment. The patient died fifteen days after the injury and at the autopsy there was found a luxation of the seventh cervical vertebra almost wholly reduced, but with swelling of the spinal cord both above and below a point where it had evidently been contused.

The illustration (Fig. 185), which is a photomicrograph at the level of contusion, demonstrates the extreme degree of destruction of the cord tissue. In this case the injury to the cord was easily detected at the autopsy by inspection, though in other cases, where the lesion may be quite as severe, the cord appears almost normal.

There is no doubt that a laminectomy without opening the dura is an entirely unwarranted proceeding, both in cases of suspected neoplasm and in contusion of the spinal cord. This may savor somewhat of a truism, but literature is not lacking in cases where the surgeon has failed to open the dura because everything appeared normal.

A frequent condition concomitant with contusion is hematomyelia. This lesion may occur synchronously with the contusion or be secondary to the local injury involving the blood vessels of the segment. It may be said that in severe contusions one almost invariably finds hemorrhagic foci varying from microscopic to macroscopic size. As has been noted in the discussion of hematomyelia, the gray matter is the most prone to show this hemorrhagic lesion. Of course, when there is a condition of contusion equivalent to transverse lesion of the cord, it will mask completely the symptom of sensory dissociation seen in the uncomplicated hematomyelia involving the gray matter. A good example of contusion with associated hematomyelia is the following from Allen:

A male, *aet.* 59, fell from a wagon, striking on his head. For about an hour he was able to walk, after which time he became completely paralyzed. Loss of sensation extended up to the third rib and there was weakness of the intrinsic muscles of the hands. He died on the day after his injury, and the illustration (Fig. 186) shows the hemorrhagic lesion present in the first thoracic segment.

The *postmortem* record states: Fracture of sixth cervical vertebral body. Fracture of the laminae of the fifth and sixth cervical vertebrae. Ligamentous rup-

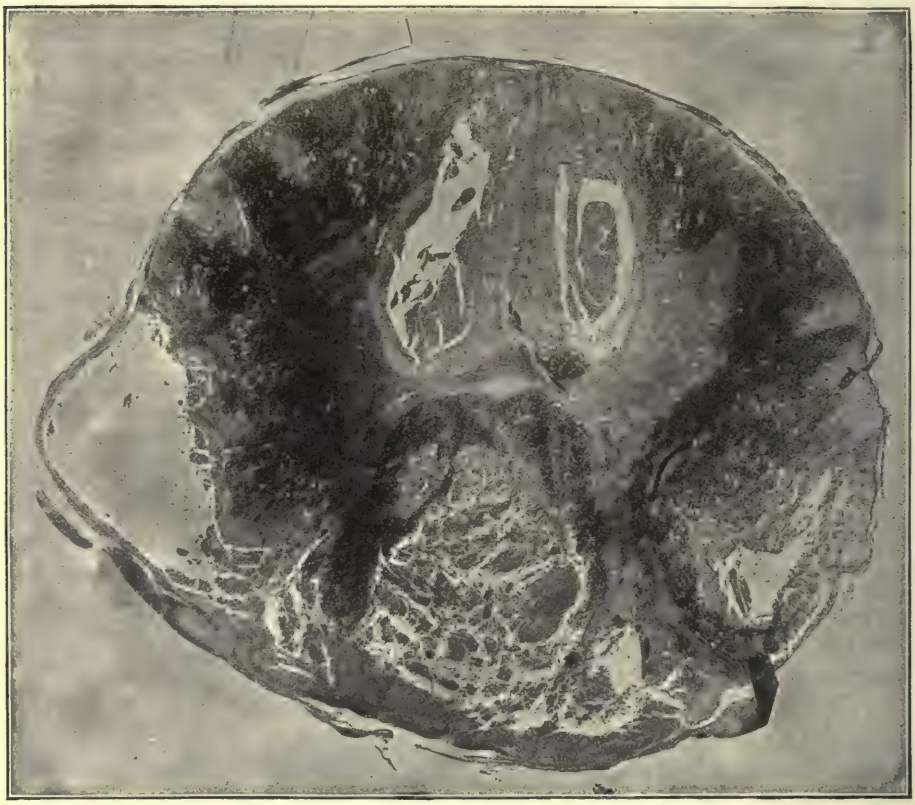

FIG. 185.—A SECTION OF THE SPINAL CORD IMMEDIATELY ABOVE THE SEAT OF COMPRESSION, SHOWING INTENSE DEGENERATION AND DISINTEGRATION OF CORD SUBSTANCE. (Allen.)

ture between sixth and seventh spinous processes of the cervical vertebrae, also between second and third thoracic vertebrae. Transverse fracture of the sternum. The musculature over the sixth, seventh and eighth cervical vertebrae infiltrated with blood. The part of the cord overlying the fracture is slightly compressed and softer in consistency than portions either above or below.

There was in this case a certain amount of compression. But the most interesting point is that he walked for an hour immediately subsequent to the trauma. This is an interesting example of a very mild contusion to which was added the factor of a progressive hematomyelia.

When the hemorrhagic change had become sufficiently pronounced, complete paralysis developed.

Edema of the substance of the cord is the most constant appearance in the early stages after contusion. If the lesion be severe enough a hemorrhagic picture is added. In the course of time, if the patient live

FIG. 186.—CROSS SECTION OF THE SPINAL CORD AT THE FIRST THORACIC SEGMENT IN A CASE OF FRACTURE-DISLOCATION, SHOWING A DIFFUSE HEMORRHAGIC PROCESS. (Allen.)

long enough, secondary softening takes place. This is evidenced by swollen axis cylinders and medullary sheaths, chromatolysis of the nerve cell bodies, wandering endothelial elements, fatty granular cells and much broken down detritus. It may be that in some of the cases showing hemorrhagic change, this has occurred when the process of softening has reached an advanced condition, but in the last case noted this is precluded on account of the short time intervening before death.

LACERATION OF THE SPINAL CORD

Laceration of the spinal cord may be caused by gunshot injury of the spine, stab wound of the spine or fracture-dislocation of the spinal column. In the latter case we must presuppose a greater amount of displacement than in the cases in which merely contusion is the concomitant neurological injury. On account of the little amount of room between

the spinal cord and the spinal canal in the thoracic vertebrae, when we have any decided amount of vertebral displacement in this region, we are very likely to have laceration of the cord.

In laceration of the cord, if the section be complete, there is a symptom picture of complete transverse lesion. Though it is unfortunately impossible to say in a given case of transverse lesion of the cord that the lesion is not a contusion of moderate degree, yet we can say most definitely

Fig. 187.—A Section from about the Ninth Thoracic Segment in a Case of Contusion of the First Lumbar Segment. (Allen.)
Compare relative degeneration in posterior columns with that in Fig. 188.

that when there are any symptoms which point to function, sensory or motor, below the level of injury, the lesion is not a complete laceration, and this is about as far as we can go.

The pathological picture of a laceration of the cord varies according to the time which has elapsed since the trauma. Immediately after the injury the vessels on the periphery of the cord are engorged with blood and in the white matter of the lateral, anterior and posterior columns there seems to be an undue separation of the elements, owing to the edema of the segment in question. If the trauma has been of any degree of severity,

there is almost always some evidence of at least microscopic hemorrhage. Later on there is evidence of secondary change in the injured segment. Large fatty granular cells appear and the blood vessels seem packed with erythrocytes; the edema has increased in the white matter and minute, hemorrhagic foci are frequently found. As elsewhere stated, the condition of hemorrhage, if one include the microscopic hemorrhage, cannot be avoided; even in the condition of contusion it is practically invariably present. Naturally, laceration of ascending pathways in the cord leads

FIG. 188.—SECTION OF THE SPINAL CORD AT THE EIGHTH CERVICAL SEGMENT IN A CASE SUFFERING A CONTUSION OF THE FIFTH THORACIC SEGMENT. (Allen.)
Compare relative degeneration in posterior columns with that in Fig. 187.

immutably to ascending tract degeneration, while laceration of descending tracts is followed by descending degeneration. In case the patient lives for six months or more, examination of the spinal cord above and below the level of injury shows clearly defined areas of degeneration. It is worthy of note that the degeneration in the posterior columns becomes narrower and more centrally placed the further we ascend above the level of injury, as entering posterior roots above the level of injury displace the injured fibers of the posterior columns toward the median septum. This point is well illustrated in Figs. 187 and 188.

When the laceration involves only a small margin of the spinal cord, the prognosis as to life is guardedly favorable. The prognosis as to return of function in the lacerated part is absolutely unfavorable with the single exception that often in lacerations approximating a hemisection of

the cord, there is a return, more or less complete, of tactile sensibility. The reason for this is the fact that tactile stimuli may pursue either one of two pathways upward in the spinal cord. The path of most importance is in the posterior column of the same side, but there is a possibility of transmission of tactile stimuli by way of the anterolateral tract of the opposite side in conjunction with the thermic and pain senses. This is the reason why the tactile symptoms in Brown-Séquard paralysis are rarely well marked.

Diagnosis is very often impossible in cases of laceration; especially is this the case in fracture-dislocation of the spinal column. We may be helped by the roentgenogram, which may show so much displacement between two vertebrae that we must postulate a laceration. Of course, in the case of a stab wound of the spine, followed by paralysis of one or both sides, we are justified in considering the diagnosis of laceration assured. But in gunshot wound of the spine the same cannot be said, as often the bullet contuses the cord without even opening the dura mater.

EXPERIMENTAL OBSERVATIONS ON CONTUSION OF CORD

In order the more thoroughly to understand the symptomatology, pathology, prognosis and treatment of contusion of the spinal cord it is well to turn our attention to the experimental studies of Allen. The genesis of this work was an attempt on the part of Allen to corroborate or disprove a statement made by some physiologists of the past generation to the effect that a median longitudinal section of the spinal cord of the dog would cause a spastic paraplegia. Were this statement true, it would indicate that the motor neuron systems in the dog were essentially different from those in the human being. After performing a laminectomy, under full ether anesthesia, he made a median longitudinal incision two centimeters in length in the lower thoracic region. When the animal came out of ether it was able to stand and walk, the only weakness noticeable being a bilateral toe-drop of very short duration in the hind limbs. This toe-drop is frequently seen in operations not involving the spinal cord and had no topical significance in this case. The instrument used in these cases was a very sharp, cataract knife and great care was taken to confine the incision to the median line. Realization of the facts that this operation, *per se,* was unaccompanied by any very definite neurological loss of function, and that in cases of contusion of the spinal cord in fracture-dislocation of the spinal column there is evidence of great intramedullary pressure on account of the edema and extravasation of blood, naturally led to the question whether this means might not be used to relieve the pressure by draining the injured segment. In this way it might be likened to the incision of a phlegmon or a decompression.

In order to make this research of value to the clinician it would be necessary to study first the effect of different impacts on the spinal cord, and determine, if possible, how great an impact the cord might suffer and yet recover function without operation. To this end an instrument was constructed which could drop a weight of 30 grams from a given number of centimeters on the spinal cord, laminectomy under full anesthesia first being performed, but the dura remaining intact and unopened. The amount of impact was reckoned as the product of the weight (30 gm.) and the height in centimeters, and was consequently spoken of as so many gram-centimeters of impact. It was found that when the spinal cord was subjected to an impact of anything below 340 gram-centimeters, one could prognosticate a complete recovery without operative interference. To be sure, there would be present for a greater or less time a condition of spastic paraplegia, varying in intensity directly with the amount of impact. But in the cases below 340 g.-cm., in two or three days, function would begin to return and in several weeks the animal would be completely restored. In these cases in which function returned without operative interference, Allen termed the trauma *hypo-impact.* He found that when the amount of impact was increased beyond 340 g.-cm., the paraplegia was permanent and that the greater the impact, the more severe was the symptom picture. Impacts of 420 g.-cm. produced a complete, spastic paraplegia with scissor-like crossing of the hind limbs, followed by emaciation and trophic disturbances as well as complete paralysis of the bladder and rectum. Impacts of 450 g.-cm. would be followed by an asthenic state quite analogous to that so often seen in the human subject with a severe traumatic lesion of the spinal cord, and death would inevitably intervene at the end of several weeks. Therefore in all cases in which the impact was over 340 g.-cm., Allen termed the trauma *hyperimpact.*

The question that now presented itself was: Could the result of the impact be benefited by a median longitudinal incision through the contused area? In order to draw a positive conclusion concerning this method of procedure it would be necessary to have a hyperimpact of such magnitude that there might be no doubt as to the end result without operation. To this end a hyperimpact of 540 g.-cm. was used, this being 90 g.-cm. more than would cause eventual death without operative interference. Two hours after this injury a median longitudinal incision was made and the animal was allowed to recover. There was, naturally, a severe degree of paralysis of the hind limbs which persisted for several weeks. But the picture never became so severe as in the non-operated cases, and after the passing of several weeks there would be evident signs of resumption of function. In two or three months the animal would be quite recovered, with ability to run and jump and, at the worst, with only some slight ungainliness in the action of the hind limbs (Figs. 189 and 190).

Let us now turn our attention to the appearance of the spinal cord

immediately after receiving the impact. This was observed under the magnification of a reading glass. Almost at once the area struck by the descending weight would become deep bluish red in color. On raising the dura with a fine tenaculum and incising it carefully so as not to wound the pia-arachnoid, there would bulge out of the incision a mass greatly engorged with blood—the pia-arachnoid. If this were torn, there would ensue free hemorrhage; and by clearing it away the spinal cord

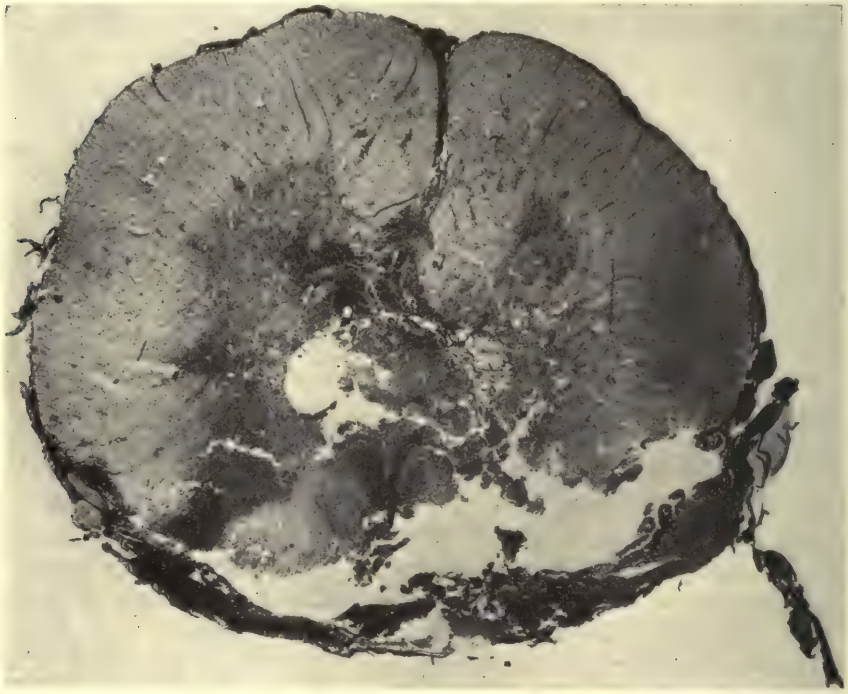

FIG. 189.—CROSS SECTION OF SPINAL CORD SIX HOURS AFTER THE HYPER-IMPACT OF 540 GRAM-CENTIMETERS. (Allen.)

In this case there was no median longitudinal incision through the injured area. The loss of cord substance is due to the extremely disintegrated condition of the tissue.

itself would be brought into view. The cord at the level of impact would present a slightly deeper tint of salmon pink and on magnification, as above described, it would be evident that the engorgement would not be confined to the pia-arachnoid, but would also involve the substance of the cord. The rapidity of this reaction of the blood vessels was altogether remarkable, two or three seconds sufficing for the pia-arachnoid to become a deep beefy red mass.

The cross section of a spinal cord at the level of impact, fifteen minutes after the trauma, showed a dense packing of erythrocytes in the blood vessels of the pia-arachnoid, of greater degree anteriorly than pos-

teriorly. According to Allen's description: "These erythrocytes appear to force themselves into every available cleft and in some places, particularly in the neighborhood of the posterior roots, there seems to be actual continuity between this annular zone of erythrocytes and miliary hemorrhagic conditions in or near the tip of the posterior horn of gray matter."

There also were many minute hemorrhages showing a predilection to

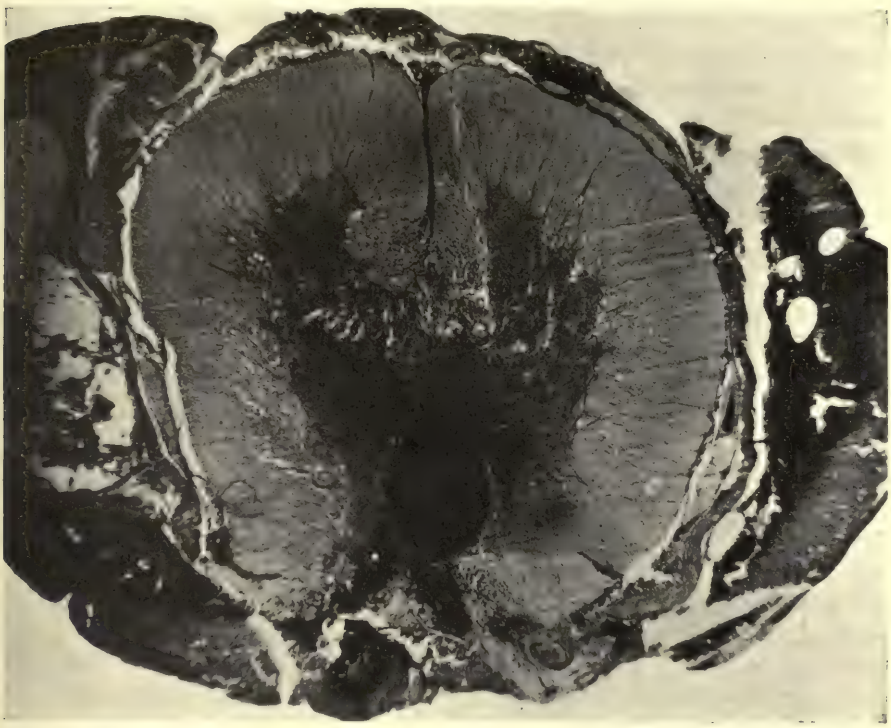

FIG. 190.—CROSS SECTION OF SPINAL CORD SIX HOURS AFTER THE HYPER-IMPACT OF 540 GRAM-CENTIMETERS. (Allen.)

In this case the operation of median longitudinal incision was performed two hours after the impact. The section shows the blood pouring out of the cord substance posteriorly, into the subdural space. The excellent preservation of the cord is quite obvious.

the posterior horn of gray matter and also, to a less extent, to the posterior columns. At this early stage there was decidedly more hemorrhage in the gray matter than in the white. Even as early as fifteen minutes after the trauma the edema in the substance of the cord had begun.

One hour after the impact the annular zone of erythrocytes in the pia-arachnoid had perceptibly diminished. But by far the greatest change was that in the gray matter of the cord. Here there seemed to be a complete groundwork of erythrocytes. Often there would be no part of

the gray matter which was not involved in this process. In the white matter there would be areas of hemorrhage, in the lateral columns as well as in the posterior columns. The anterior cornual cells of the injured level even one hour after the injury would begin to show a deterioration in staining capacity. These various findings would increase as time went on, and by four hours after the trauma one of the most interesting findings was the presence of swollen axis cylinders in the lateral and posterior columns. Hour by hour the disruption in the substance of the spinal cord would become more apparent, and histological specimens prepared six hours after the trauma, when the 540 g.-cm. impact was used, would lack much of the substance of the cord because it had flowed away in the technical preparation. This is very likely a greater degree of contusion than frequently obtains, but it was used in Allen's experiments so as to be sure to have a trauma sufficiently severe to make a good basis of opinion as to the operative treatment.

One of the most interesting points in all this work for the clinical surgeon is the proof of the progressive character of the lesion in cases of contusion of the spinal cord. We should ever bear in mind that the condition of the injured segment when we examine the case one hour after the accident is in all probability a very different one from what obtains at a subsequent examination, let us say three hours later. Allen considers that in all cases of contusion of the cord there are two factors to claim our attention: (1) the actual destruction of tissue at the time of the impact; (2) the secondary changes due to "the outpouring of serum and blood into the substance of the cord." Concerning the first factor, we might say that it is beyond our power to obviate the destruction of substance immediately at the time of the crush injury. Some have, to be sure, advised the suturing of a severed spinal cord, holding that a functional rehabilitation was a possibility. In the light of modern investigation it may be definitely stated that without neurilemma nuclei one cannot expect any resumption of continuity in severed nerve tracts, and the tracts of the spinal cord not possessing neurilemma sheaths, naturally, such repair is out of the question. There have been undoubted cases in which the spinal cord has been completely severed and subsequently sutured with a preservation of life on the part of the patient. But that the junction of the severed ends is ever more than scar tissue, is quite beyond argument.

We, therefore, turn our attention to the second factor—the secondary change in the cord substance due to the edema and hemorrhage—and at once the question arises: Is there possibly a time when by an incision through the contused level we could drain it of these products, thus relieving the tissue of a great amount of intramedullary pressure, to say nothing of the possible effect of the chemical irritation to which the nervous tissue must be subject in the involved segment. On the latter point

Allen founds the *raison d'être* of his operation. In the case of the spinal cord subjected to a hyperimpact of 540 g.-cm. and two hours subsequently being operated on by means of the median longitudinal incision, the histological study of the injured area shows that there has not occurred the great breaking up of tissue in the lateral columns and wholesale destruction of the gray matter which we find in the non-operated cases. On the contrary, we find that there is a passage of the hemorrhage and exudate posteriorly through the incision, and the tissue to either side of the incision offers an appearance not very far from normal.

It has been suggested by some who are fearful of undertaking so radical a procedure as the longitudinal section of the spinal cord, that one reason against the method is the fact that, as Halstead and Vaughn state, "Such incisions, of necessity, must cut decussating fibers, if carried deeply, and will, therefore, produce symptoms easily demonstrable in man, even if they are not in the dog."

Of course, reference to any modern work on physiology will demonstrate how untenable this criticism is. At the most the length of the incision would not have to be over one and one-half to two centimeters and the overlapping of cutaneous segmental distribution would allow of no sensory disturbance whatsoever. Let us suppose, though, that such was not the case; at the worst there would be a small cutaneous band of thermo-anesthesia and analgesia corresponding to the segment incised, a symptom, "easily demonstrable," to be sure, but hardly of sufficient weight to constitute a contra-indication to the method if it offer any promise of saving life.

The reason for making the incision in the median line and not, as has been lately suggested, from the tip of the posterior horn inward and forward, is that the amount of damage to the gray matter in the latter case might be of some import. In making the incision in the median line, one destroys the least amount of important tissue. Time and experience on human material will alone prove whether this method is to receive a permanent place on our list of justifiable surgical procedures. The few cases which have been treated by this method give promise that much good may accrue from its use. This is also indirectly suggested by the success which has followed in a number of cases in which the spinal cord has been incised for other reasons—notably in the extrusion method of dealing with intramedullary tumor.

Based upon these experimental observations we may say that in all cases of contusion of the spinal cord we are always confronted with the impossibility of a definite prognosis immediately after the trauma, as the symptoms in this early stage may be just as severe for a mild lesion as for a very severe crush. Unfortunately we cannot escape from the feeling that more harm is done by the expectant treatment in these cases than in an exploratory laminectomy. Whether we decide to make a median longi-

tudinal incision into the cord after we have exposed it, we may leave for the appearance of local conditions to decide. The feeling concerning exploratory laminectomy is much the same to-day as was that concerning exploratory laparotomy twenty years ago. There is every reason to hope and expect that as experience grows in this regard, the opening of the spinal canal for diagnosis and treatment will no longer be the subject of

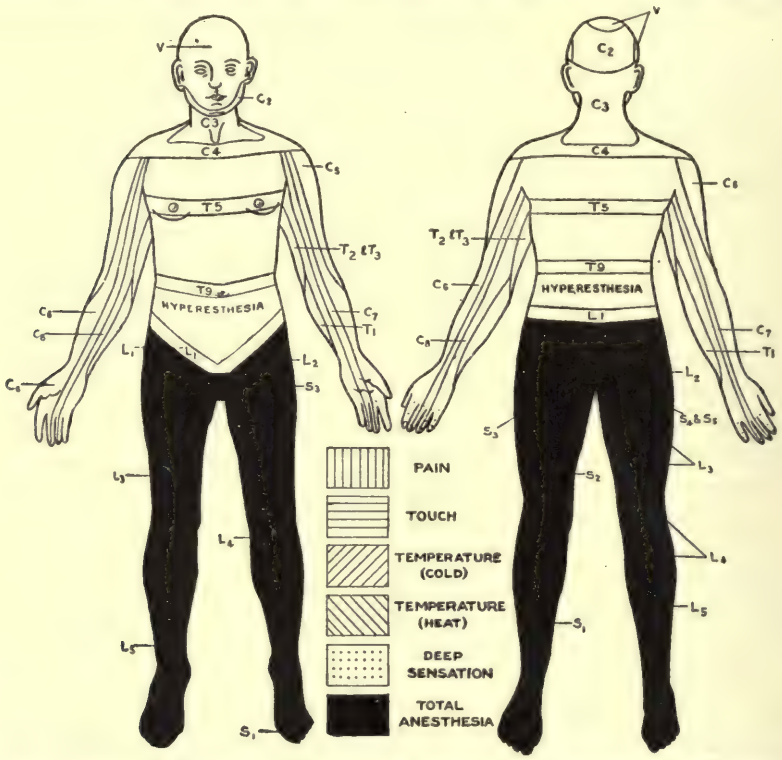

FIG. 191.—CHART OF SENSORY DISTURBANCE BEFORE LAMINECTOMY AND CHORDOTOMY. (University Hospital, File No. 18877.)

the opposition which it now so frequently meets. The following history illustrates two points in the above experimental considerations: On making the median longitudinal incision, there was evidence of great tension and through a period of six weeks there was a gradual improvement in the conduction of sensory impressions through the injured level of the cord, manifested by return of sensation in the lower limbs. The ultimate states of the patient would demonstrate to us that the first factor, the actual and immutable damage at the time of injury, was too great to be overcome by any means.

Fracture of the ninth thoracic vertebra with contusion of the cord and evidence of complete transverse lesion. Laminectomy and median

chordotomy with partial recovery of sensation but continued incontinence of urine and feces, and development of spastic paraplegia.

The patient, a boy, *aet.* 15 (File No. 18877), fell from a second story roof, striking the branch of a tree in his fall to the ground, two hours before admission to the University Hospital, July 16, 1912. Examination immediately after admission revealed an area of anesthesia from one inch below the umbilicus to the

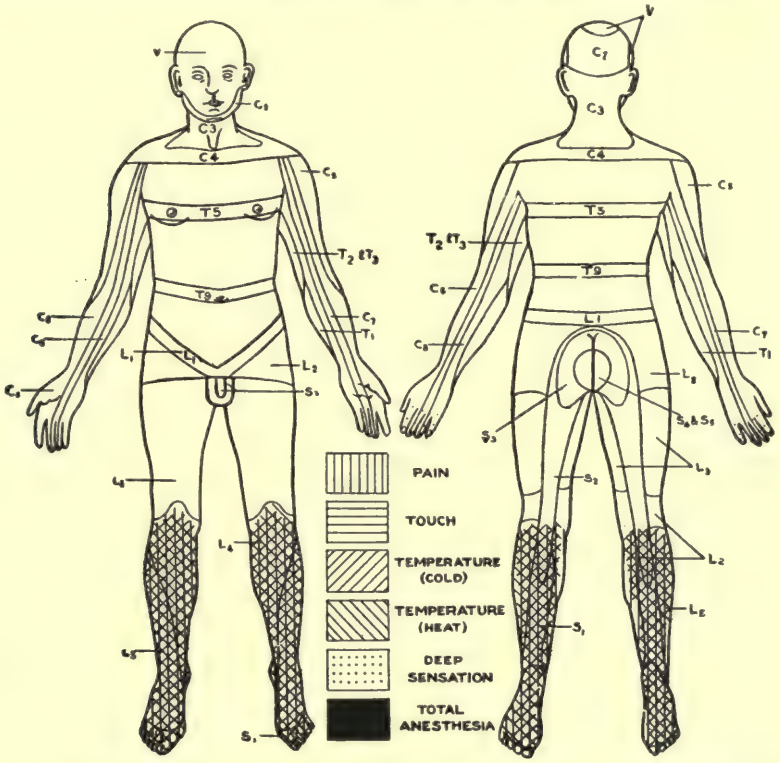

FIG. 192.—CHART OF SENSORY DISTURBANCES AFTER LAMINECTOMY AND CHORDOTOMY. (University Hospital, File No. 18877.)

symphysis pubis, but below this point there was complete loss of all forms of sensation (Fig. 191), complete paralysis of both extremities and absence of all reflexes. Preparation was made at once for operation.

Laminectomy. Under endotracheal anesthesia the spinous processes and laminae of the eighth and ninth thoracic vertebrae were removed. The fracture involved the ninth thoracic vertebra, but there was no encroachment upon the spinal canal and no pressure on the cord at the time of operation. Upon opening the dura at this level the cord was found to be swollen, and a median incision in the cord 1 cm. long was followed by a gush of blood, evidently under considerable tension. The dural incision was partly closed with three interrupted sutures far enough apart to allow the escape of blood or cerebrospinal fluid.

About six weeks after the operation the following condition was found: Pin prick could be recognized in the lower third of the right leg and foot and in the

upper external surface of the thigh. The internal and anterior surface of the thigh was completely anesthetic, as was also the upper two-thirds of the leg. In the lower left extremity sensation to pain was present over a band running down the inner surface of the thigh and the inner surface of the lower portion of the leg and on the foot. The anterior and external surfaces of the leg were completely anesthetic. Tactile sensation was well preserved in the left leg below the knee. Ten weeks after the accident the condition of sensory disturbance had changed but little, except that tactile sensation had been restored in both legs below the level of the knee (Fig. 192). There was no return of motion in either extremity. In the course of the next few months the lower extremities became spastic and at the time of the patient's discharge from the hospital, eight months after the accident, there was still incontinence of urine and feces and no further return of sensation.

SYMPTOMATOLOGY OF COMPLETE AND PARTIAL CORD LESIONS

In discussing the symptomatology we must keep several points of view in mind. In the first place, there is the question of whether the injury to the spinal cord is complete or incomplete. Then we must remember that unfortunately the immediate symptom picture in fracture-dislocation of the spinal column is often misleading. After spinal trauma there is very apt to be the syndrome of complete solution of continuity of the spinal cord: all reflexes below the level of lesion will be abolished; loss of voluntary control of the bladder and rectum obtains; total loss of all forms of sensation up to a certain segmental distribution will be found together with a complete flaccid paralysis of all voluntary muscles below the level of injury. Let us suppose that this picture is found in a man who an hour or so before the examination has sustained a serious accident involving his spinal column; the question that presents itself is: Can we make a positive diagnosis that there has been a complete transverse lesion of the cord? This question must be answered in the negative. All of these symptoms may be due to a complete solution in continuity of the spinal cord, but it is a well recognized fact that the entire group may also be a temporary expression of what we may term, for want of a better nomenclature, *spinal shock*. The surgeon who makes a diagnosis of complete lesion of the cord may be somewhat embarrassed by finding in the course of one or more days that there is an unmistakable return of deep sensation in the lower limbs, that the patient is able to feel the passage of urine through the urethra and that slight motion of one or both ankles is possible. Such a condition at once nullifies the original diagnosis, and such an occurrence is not infrequent. Now, were the treatment of fracture-dislocation of the spinal column purely expectant and nonoperative, the mistake in diagnosis would be of little moment. But the minute we are confronted by this grave injury, the question of prime importance is whether to operate or treat by the expectant plan. Until recently, conser-

vative advice has favored waiting long enough to see whether the sensory and motor symptoms persist unchanged, and this might entail several days. But the work of Allen in experimental impact to the spinal cord makes it clear that while we wait in these cases, the condition of edema and hemorrhage in the substance of the spinal cord may work an irretrievable damage. This is a disquieting thought. On the one hand we are confronted with the possibility of performing a laminectomy on a but slightly injured patient; on the other, with waiting until a possibly tractable local condition becomes hopeless. The arguments for and against early operation will be adequately discussed under treatment, but it is well to state the question here in order to accentuate the fact that the entire examination and consequent estimate of the injury will form the only tangible and objective grounds on which we can make up our minds as to proper procedure.

In cases of contusion and laceration of the spinal cord, the earliest examination is the most important, and as a corollary to this proposition we can say that the earlier this examination, the better. It is of common occurrence to find that the surgeon who sees the patient six or eight hours after the injury will chart a very different level of sensory disturbance than did the physician who made the examination one hour after. To be sure, this would not be an important matter did the roentgenogram always show the level of bony injury. But in a percentage of cases the roentgenogram may fail to locate any skeletal lesion and in such a case the surgeon is forced to make his selection of two opinions: the first, that based on the examination immediately following the injury, possibly neither meticulous nor trustworthy; the second on his own opinion or that of the neurologist based on data which may have materially changed since the reception of the injury.

Therefore, in a sentient case, the sensory examination should be made as soon after the accident as possible and a definite line in ink or some indelible substance should be drawn on the patient's skin limiting the upper border of tactile and pain disturbance. I take it for granted that in the vast majority of cases the patient will not be examined first by a neurologist, for which reason I suggest that the examiner should concentrate his efforts in the study of tactile anesthesia and analgesia. The testing for thermo-anesthesia is a more difficult technic, and so far as the involvement of the crossed tracts in the cord is concerned, we obtain a very satisfactory picture from the study of the analgesic level. It is important to be able to state definitely whether immediately after the injury the patient was able to move any part of either lower extremity; it bears upon the question of primary complete solution of continuity. In using the term "complete solution of continuity" I do not mean necessarily a complete physical break in the spinal cord, but rather an injury of such severity that no impulses pass either upward or downward through the injured

level. It makes a great deal of difference in our estimate of the situation, even though there is absolute motor paralysis of the lower limbs, when we examine the patient ten hours after the accident, if we are told on credible authority that half an hour after the injury the patient was able to flex an ankle slightly.

It should be noted whether there has been an involuntary evacuation of the bladder immediately subsequent to the injury, and in any case careful catheterization under the most cleanly conditions should be performed and the urine examined for blood. Let us suppose that no blood is found, but that after twenty-four hours hematuria obtains. In this case Allen advances the following explanation: Immediately after the trauma there is an anemia of the kidney with consequent lowering of the vitality of the kidney substance; "the vascular equilibrium being restored, the kidney finds itself supplied with blood, which, on account of a badly damaged parenchyma, it cannot handle, and hence the hematuria." A partial control of the bladder and rectum, that is to say, an ability on the part of the patient voluntarily to relax or contract the external sphincters, is presumptive evidence that the spinal cord lesion is not complete; but the reverse condition—total loss of sphincter power—is not a sign of complete solution of continuity. In fact, there are many cases in which it is evident that the lesion is incomplete and in which there is total loss of bladder and rectal control and yet positive signs of sensory and motor function through the injured segment. In such cases, at times, the restoration of bladder and rectal function may be long delayed.

Preservation or increase of tendon reflexes below the level of injury argues in favor of an incomplete lesion, as does also a loss of all reflex activity which later is replaced by reflex function. But a preservation of reflex activity, which in several days gives place to total loss, is an argument that secondary processes in the cord substance, edema and hemorrhagic softening, have converted an incomplete into a complete transverse lesion.

In injuries of the spinal column causing contusion or laceration of the spinal cord the question of operation is all-important. Unfortunately, great difference of opinion exists as to the legitimacy of operation as an early procedure in most of these cases, and this position is based upon two factors: first, the question of efficacy of operation in any case; second, the inability to determine, in the early hours following the trauma, whether the cord lesion is complete. As we have noted elsewhere, this latter factor is of great moment, and in order to emphasize the contrast which may obtain the following parallel tables are given.

The differential diagnosis between complete and incomplete or partial lesion of the spinal cord may be formulated as follows:

Complete	Partial
Usually flaccidity of all muscle groups whose innervation comes from segments below the level of injury. Paralysis is complete.	A spastic condition with or without contractures of muscle groups whose nerve supply comes from segments below the level of injury. Paralysis may not be total.
Loss of reflexes whose arcs lie in segments below the level of injury.	Increase of reflexes whose arcs lie in segments below the level of injury. Presence of the Babinski phenomenon.
Complete loss of control of bladder and rectum which is demonstrated either by constant dribbling or else by periodic evacuation without knowledge or volition.	A possible partial control of bladder and rectum with at times knowledge on part of patient that evacuation is taking place.
Complete loss of all forms of sensation of a sharp segmental distribution.	Loss of sensation is not absolute, in that patient often perceives strong stimuli of protopathic nature and is at times able to detect change in position.
The symptom picture is stationary, with tendency toward trophic change for the worse.	The symptom picture is not necessarily stationary and a gradual improvement may be noted.

An examination made immediately after an injury may give the symptom-complex of a complete transverse lesion, and in the course of time the restoration of function is an evidence of the fact that the tracts were not irreparably damaged. It is evident, therefore, that there is always the possibility of error when one attempts, shortly after an injury, to give an accurate prognosis.

Reference to the chapter on Physiology will show the various segments of the spinal cord through which run the numerous reflex arcs. It is often possible to locate the level of cord injury by observing the lowest segment through which the reflex arcs are unimpaired. It should be remembered that in incomplete transverse lesions, although the reflexes may be greatly exaggerated below the level of the lesion, yet through the injured segment the reflexes are abolished. This will help us only in those cases in which the injured segment carries the synapse of some well recognized reflex arc.

At times the diagnosis of the level of injury is aided by the position the patient assumes. Thorburn in his classical "Contribution to the Surgery of the Spinal Cord" has described three prototypes, corresponding to injury of C_5, C_6 and C_7. His picture of the position assumed by the patient in whom the sixth cervical segment is crushed has been reproduced in almost every book dealing with the subject (Fig. 193). His picture, illustrating the position in an injury to the seventh cervical segment, is chiefly interesting in that it shows a level of truncal anesthesia which frequently confuses the physician who is not *en rapport* with seg-

mental distribution. It will be noticed that though the seventh cervical segment be injured, yet the level of anesthesia, if followed from below upward, disappears at the upper level of T_2, while if normal sensation be followed downward it disappears at the lower level of C_4. This seeming incongruity is at once understood when we realize the neuromeric arrangement in fetal life due to the appearance of the limb buds. In other words, there is no truncal representation of C_5, C_6, C_7, C_8 and T_1, the sensory distribution from these segments going to the upper extremities. This is so important a point that no one can afford to ignore it.

FIG. 193.—POSITION OF THE UPPER EXTREMITIES IN A COMPLETE TRANSVERSE LESION OF THE CORD AT THE LEVEL OF THE SIXTH CERVICAL SEGMENT. (After Thorburn.)

We shall consider the symptom pictures of cord injuries involving C_4, C_5, C_6, C_7, T_9, L_2 and L_3. It is necessary to consider a spinal lesion in the lowest thoracic and upper lumbar region as affecting two segments of the spinal cord because in the lumbosacral enlargement the segments are so diminished in length that the bony lesion is practically sure to involve more than one. We shall also assume that the bony lesion has caused a complete transverse injury to the spinal cord, remembering that this does not necessarily mean that the cord is actually cut in two, but that its physiological continuity is broken. We are occasionally chagrined to find that the x-ray examination places the lesion of the bone at a level quite at variance with what we deduce from the subjective symptoms, motor and sensory. Sometimes our neurological examination indicates a level considerably above, sometimes considerably below, the fracture. It is difficult to explain this discrepancy; the following case aptly illustrates the point:

Fracture of the fourth cervical vertebra; partial paralysis of the upper extremities; complete of the lower extremities; with recovery of sensation for all forms and recovery of motion to a considerable extent four weeks after laminectomy, at which blood stained fluid was found in the spinal canal without macroscopic evidence of injury to the cord.

The patient, a man, *aet.* 29 (File No. 24039), while unloading a coal car, fell ten feet, and in striking the ground his chin was forcibly flexed on the chest. Hasty examination before operation revealed the following conditions: The patient could move his arms in various directions, but the fingers of both hands were completely paralyzed. There was complete loss of sensation and total paraplegia of the lower extremities. The roentgenogram revealed the lesion to be at the level of the fourth and fifth cervical vertebrae. Laminectomy was performed as soon as the patient could be prepared for operation. Under nitrous oxid anesthesia the spinous processes of the fourth, fifth and sixth cervical vertebrae and the laminae of the fifth and sixth were removed. The dura was tense and vigorously pulsating. Upon incision a large quantity of blood-stained cerebrospinal fluid escaped. An inspection of the cord, however, failed to reveal any evidence whatsoever of trauma, and the wound was closed.

The interesting features of this case were the complete recovery of sensation for all forms four weeks after the accident and the partial restoration of motor function. Unfortunately, the patient developed an ascending pyelonephritis from which he died August 26, 1913, six weeks after the accident. This case illustrates an unfortunate occurrence which is not infrequent: a lack of coincidence between the roentgenological examination and the objective signs, motor and sensory. Without the x-ray we would not have hesitated to localize the damage in the eighth cervical and first thoracic segments. It is not easy to explain such a localization by a lesion of the fourth and fifth cervical vertebrae.

Injury of the Fourth Cervical Segment

The motor symptoms of injury of the fourth cervical segment are complete quadriplegia. At first this paralysis is of the flaccid type, and we are unable to say definitely whether this flaccidity is due to a complete and permanent solution in continuity or is simply the expression of what we may term spinal shock. The breaking of physiological continuity does not by any means indicate a permanent condition, but unfortunately, at first, the symptoms do not permit of a differential diagnosis. If the cord lesion, though transverse, do not completely break physiological continuity, we shall have complete quadriplegia which at first will most likely be flaccid in type, but in time spasticity will develop. This spasticity will be more pronounced in the lower than in the upper extremities. One reason for this discrepancy lies in the fact that the extreme proximity of the lesion to the cervical enlargement more readily holds the reflex arcs for the upper limbs in abeyance. As the main origin of the phrenic nerve lies in the fourth cervical segment, there will be total paralysis of the diaphragm and breathing will be costal in type.

The sensory disturbance in this case will be a complete loss of all forms of sensation up to and including the skin area supplied by the fourth cervical segment (Fig. 194). Now, an interesting phenomenon often presents itself in these transverse lesions: we frequently find that in the area supplied from the segment immediately above the injury there is some loss of the sense of pain and temperature. This is probably due to the fact that there has been some extension of a hemorrhagic process up-

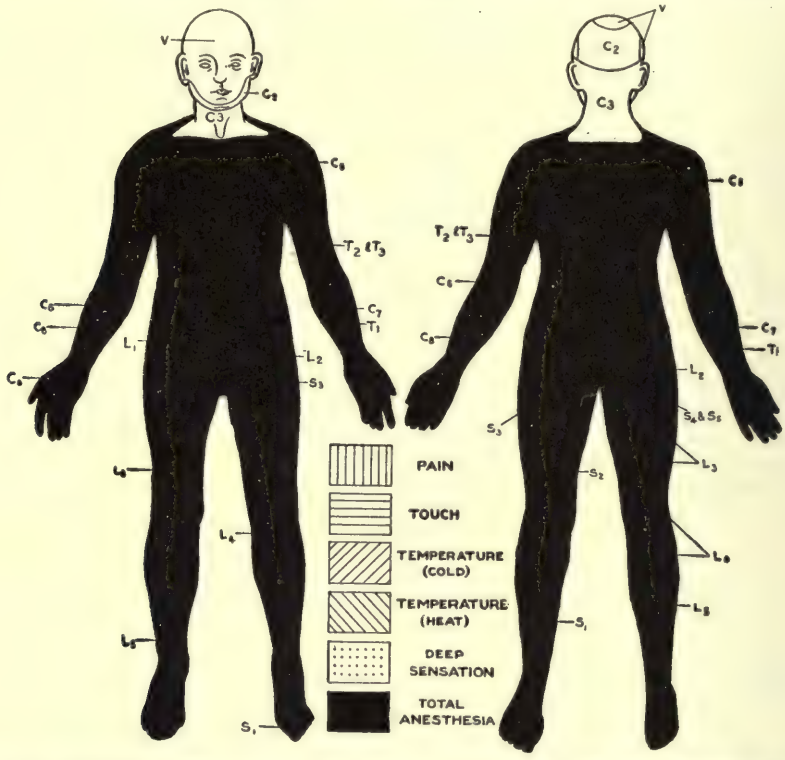

FIG. 194.—SENSORY DISTURBANCES FOLLOWING AN INJURY OF THE FOURTH CERVICAL SEGMENT.

ward in the gray matter of the cord. This extension upward may be slowly progressive so that from day to day we are able to chart new areas of analgesia and thermo-anesthesia, and when this condition obtains we should consider it an unfavorable sign.

In transverse lesions of the spinal cord situated in the cervical region we must bear in mind that the fibers from the midbrain to the ciliospinal center in the eighth cervical and first thoracic segments are cut, and that although the ciliospinal reflex shares, to a certain extent, the automatic action of the other autonomic mechanisms, yet in the cases of high cervical fracture we are likely to have bilateral contracted pupils.

Injury of the Fifth Cervical Segment

An injury involving the fifth cervical segment presents virtually the same motor phenomena as that in which the fourth cervical segment is injured, with the exception that there is an escape of the major part of the phrenic nerve and, therefore, the diaphragm is not paralyzed. The

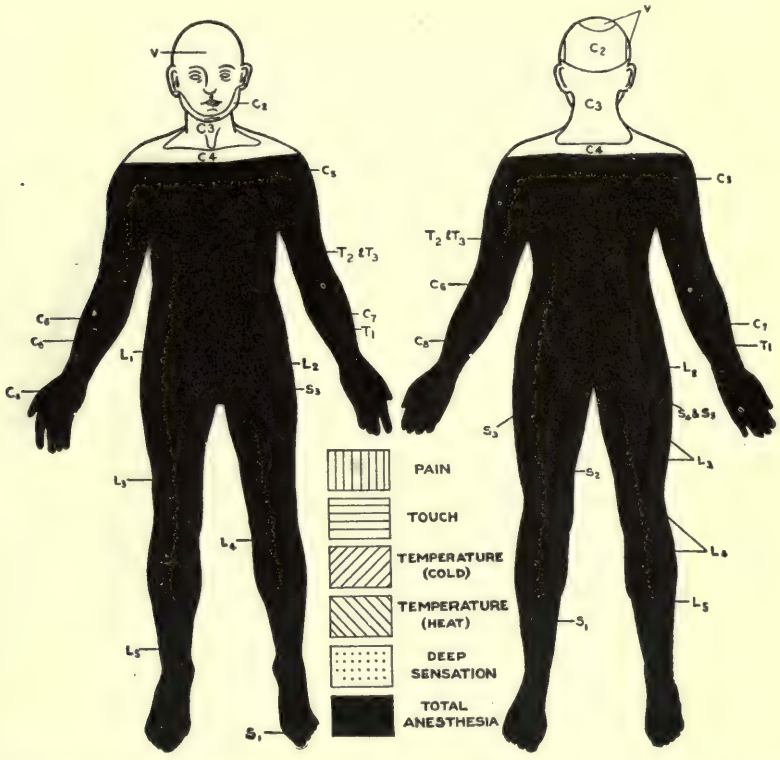

Fig. 195.—Sensory Disturbances Following an Injury of the Fifth Cervical Segment.

same sensory picture obtains as in the former case, except here the cutaneous area supplied by the fourth cervical nerves is normally responsive to tactile stimuli, presenting probably, as above stated, some degree of thermo-anesthesia and analgesia (Fig. 195).

Injury of the Sixth Cervical Segment

An injury involving the sixth cervical segment permits the escape of the uppermost root of the brachial plexus, on which account we have a partial preservation of power in the shoulder girdle. Thorburn has pic-

tured a characteristic position which a patient with such an injury will assume (Fig. 193).

The sensory changes are the same as in the previous case, with the exception that there is a preservation of tactile sense on the outer and upper surface of both arms (Fig. 196). In case the injury to the spinal cord is of light enough grade to permit of recovery of the patient, the chances are that the biceps reflex will never be regained and the paralysis

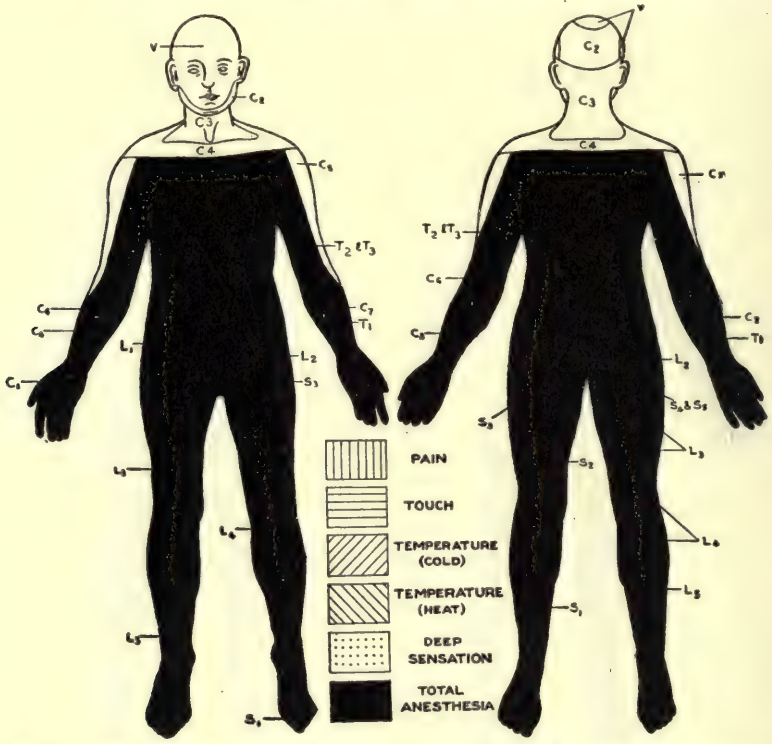

Fig. 196.—Sensory Disturbances Following an Injury of the Sixth Cervical Segment.

of muscles whose motor innervation comes from the sixth cervical segment will most likely be of the flaccid type. It is worthy of note that the truncal anesthesia in such case is just as high as in the case in which the fifth cervical segment was injured. The reason for this has already been stated, but the point is a most important one and unless understood may easily lead to a false estimate of the situation.

Injury of the Seventh Cervical Segment

An injury involving the seventh cervical segment allows the fifth and sixth cervical segments to functionate; therefore we may expect to

find a preservation of the biceps tendon reflex. In fact, at times this reflex is found exaggerated, owing to the increase in irritability of the reflex arc from the close proximity of the lesion. The sensory examination is quite distinctive, so far as the upper extremities are concerned, but the limitation of normal sensation on the trunk is still at the same level as we have noted in higher lesions. Thorburn has pictured a position assumed by a patient with this injury (Fig. 197). It will be understood

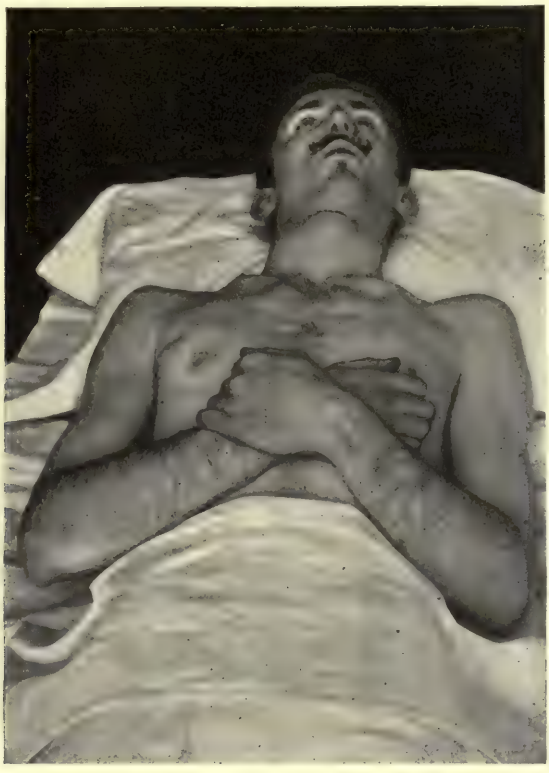

FIG. 197.—POSITION OF THE UPPER EXTREMITIES IN A COMPLETE TRANSVERSE LESION OF THE CORD AT THE LEVEL OF THE SEVENTH CERVICAL SEGMENT.

that the shoulder girdle muscles are not paralyzed and that power to flex the forearms on the arms is still preserved.

In the lower cervical lesions the mapping out of the areas of anesthesia on the upper extremities is not at all times as definite as might be wished, or as might be expected by the inexperienced from the usual textbook description. Often the boundaries of segmental distribution in the hands vary greatly from what we consider a prototype; and even if this be not so, the segmental areas are so narrow that a difference of opinion may easily obtain. A fairly constant finding, however, is the limitation of anesthesia to the ulnar side of the ring finger in cases of involvement of

the eighth cervical segment (Fig. 198). A word of warning is not amiss as to the presence, absence or change in the triceps reflex. The reflex arcs for this phenomenon pass through the sixth, seventh and eighth cervical segments and, therefore, in order to interfere completely with its function, a lesion of wide extent must be presupposed. Moreover, in normal condition this reflex varies greatly, at times being most difficult to elicit at all.

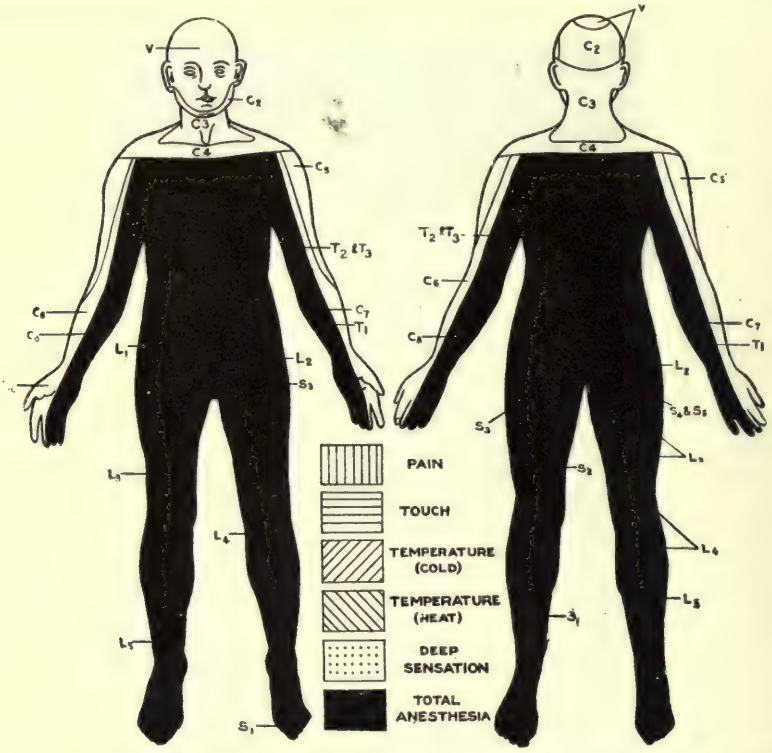

Fig. 198.—Sensory Disturbances Following Injury of the Seventh Cervical Segment.

Consequently, too much weight should not be given to the absence of the triceps jerk, and in high cervical lesions we frequently find that this reflex is not so greatly exaggerated as the biceps jerk.

Injury of the Ninth Thoracic Segment

In an injury involving the ninth thoracic segment there is of course no paralysis of the upper extremities. There is, however, a complete motor paralysis of the lower extremities which is, as in the injuries of higher levels, at first flaccid and afterward—if solution of continuity has not been complete—spastic. The sensory symptoms present the same prin-

ciples as have already been enunciated (Fig. 199). There is one point, though, which might well be emphasized: because of the extreme length of the spinal segments in this region, a hemorrhagic or traumatic softening of the gray matter immediately above the level of injury would have to be very much greater in vertical extent to cause as much thermoanesthesia and analgesia as in the cervical region. It may be for this

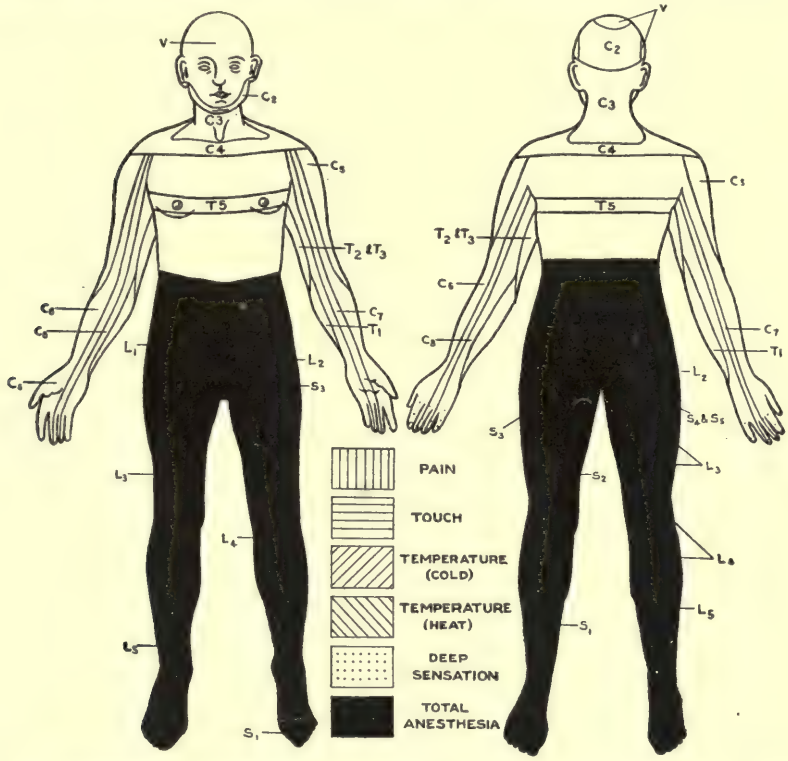

FIG. 199.—SENSORY DISTURBANCES FOLLOWING AN INJURY OF THE NINTH THORACIC SEGMENT.

reason that injuries of this level seem frequently to give sharper pictures in their sensory involvement than do the cervical or lumbar lesions.

Fracture-dislocation of the sixth and seventh thoracic vertebrae with complete transverse lesion. Laminectomy one month later revealed an area of degeneration of the cord at the level of the lesion which precluded the possibility of restoration of function.

The patient, a man, *aet.* 21 (File No. 26393), while repairing an electric arc light, received an electric shock and fell from the pole 20 feet to the ground. He was admitted to the University Hospital, April 26, 1914, five days after the accident. The following condition was noted: There was a kyphosis at the level of

the seventh thoracic vertebra, tenderness on pressure over the fifth, sixth and seventh spinous processes. There was no evidence of motor or sensory disturbance of the upper extremities. There was complete loss of sensation for touch, pain and temperature below the level of the eighth rib on either side. Between the seventh and eighth ribs tactile sensation was preserved; temperature sensation was present, though impaired, and pain sensation was lost. Between the fifth and seventh ribs there was a zone of hyperesthesia (Fig. 200). Pressure sensation was preserved over the abdomen. There was complete flaccid paralysis below the level of the

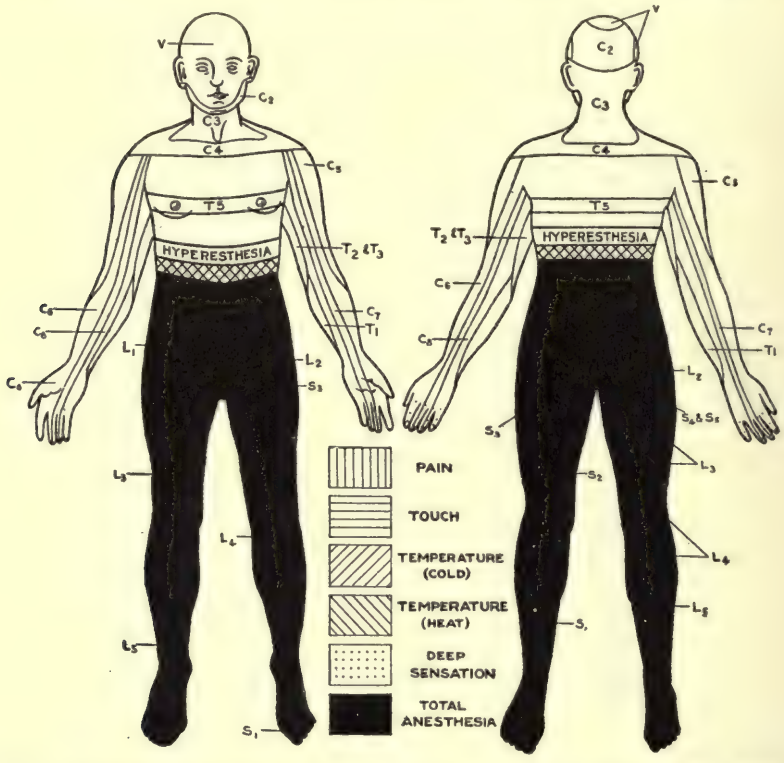

FIG. 200.—CHART SHOWING SENSORY DISTURBANCES BEFORE OPERATION IN FRACTURE-DISLOCATION OF SIXTH AND SEVENTH THORACIC VERTEBRAE WITH COMPLETE TRANSVERSE LESION. (University Hospital, File No. 26393.)

lesion, complete loss of reflexes in the lower extremities and abdomen and complete incontinence of urine and feces.

Laminectomy, April 27, 1914, under local and nitrous oxid anesthesia. Removal of the spines and laminae of the fifth, sixth and seventh thoracic vertebrae. There had been an anterior luxation of the sixth upon the seventh thoracic vertebra with rotation of the sixth toward the right and a fracture of the spine and lamina of the sixth. Upon opening the dural sac there was no external evidence of cord injury. However, a median incision in the cord was followed by the escape of a semiliquid substance, the result of cord disintegration. The dura was left unsutured at the site of injury. The patient recovered from the operation and when heard from fourteen months later there had been no return of function.

Some time after the injury, particularly in those cases in which there is a resumption of reflex activity, we can gain much useful information by the observation of the rectus abdominalis reflex. Reference to the chapter on Physiology will show that the abdominal reflex is divisible into three parts: an upper or epigastric reflex whose arc passes through the sixth and seventh thoracic segments, a midabdominal whose arc passes through the eighth and ninth thoracic segments, and an inferior abdominal having the reflex arc in the tenth, eleventh and twelfth thoracic segments. Therefore, an injury to the cord involving the ninth thoracic segment would obliterate the midabdominal reflex, while the epigastric reflex would be preserved. Ultimately, the inferior abdominal reflex would be lost or exaggerated according to the severity of the lesion. Where any reflex activity below the level of injury returned there would be, in all probability, a great increase in the inferior abdominal reflex. Where the injury to the spinal cord is not transverse but more monolateral, the appearance of the abdominal reflex may be most startling in nature, the exaggerated response on the injured side dragging the abdomen over in a unique manner.

In injuries to the spinal cord at the several levels above noted, the bladder and rectal symptoms are quite similar. It must be realized that the pathway of sensory impressions from either the bladder or rectum to the brain is interrupted and that the patient does not feel distention of either viscus any more than he feels pain and tactile stimuli below the level of injury. At first, the reflex activity below the level of injury being set aside, there is a tendency to the incontinence of retention after a certain amount of distention has occurred. With the resumption of reflex activity the bladder and rectum act automatically and the condition of spastic incontinence obtains. In lesions of the spinal cord above the first lumbar segment one is often surprised to find that quite a degree of motor control of the soma and sensory perception below the level of injury has returned before the patient is able to control in the least degree the act of micturition or defecation. Often the first sign of return of function will be that the patient feels the passage of urine through the urethra or of feces through the anus. The next step toward recovery of these powers will be that bladder distention is perceived and the patient is able to control the reflex act for a few seconds, possibly long enough to enable the nurse to procure the urinal or bedpan. This time of control in favorable cases gradually becomes longer, until it may be said that the patient has regained a practical sphincter function. Many get the idea that the act of defecation is more frequently regained than that of micturition. This is faulty observation, and the real explanation of the fact is that naturally the feces are not absolutely fluid like the urine, and that therefore there is less mechanical possibility for the involuntary discharge of the rectal contents.

Injury of the Second and Third Lumbar Segments

In involvement of the second and third lumbar segments, the motor picture is one of complete paraplegia, which, on account of lower motor neuron destruction in the upper part of the lumbosacral enlargement, has a tendency to be of a flaccid type, even though there be an incomplete solution in physiological continuity. The sensory disturbance is limited above to a line corresponding to Poupart's ligaments (Fig. 201). When

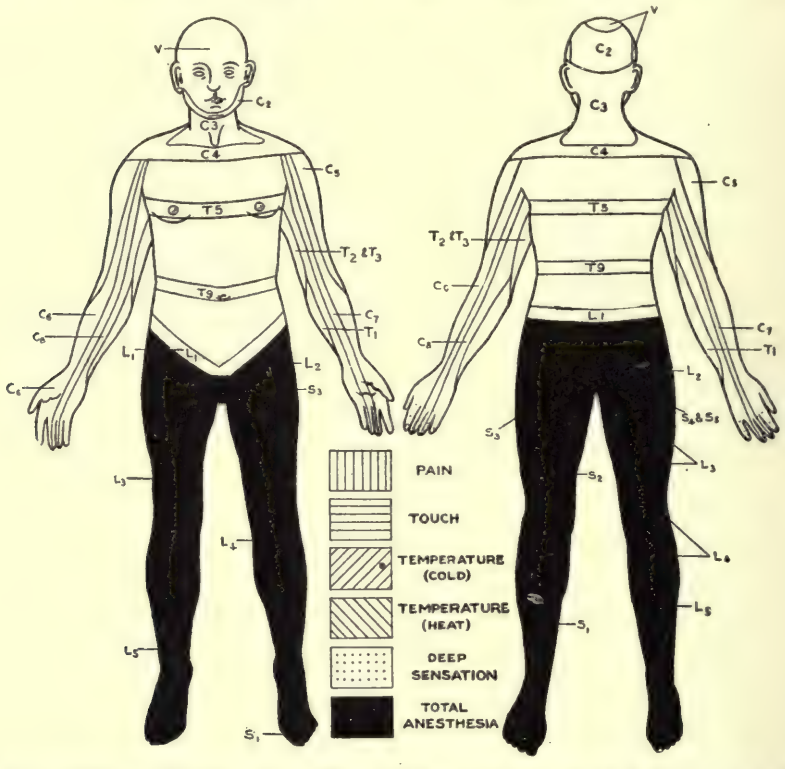

Fig. 201.—Sensory Disturbances Following an Injury of the Second and Third Lumbar Segments.

we remember that the two important centers of micturition and defecation are located in the first and second lumbar and the second and third sacral segments, we easily understand that the disturbance of bladder and rectal function is of more profound character. As a matter of fact, the pure reflex and involuntary emptying of the bladder and rectum is not so frequently seen in these low lesions. The incontinence of retention and, later, complete incontinence, are of more frequent occurrence.

The Brown-Séquard Syndrome

In fracture-dislocation of the spinal column due to extreme lateral bending or to torsion, it happens at times that the injury to the spinal cord is not a complete tranverse lesion, but rather a contusion involving more or less definitely one-half of the cord. Now, although such a lesion never approximates in exactitude a hemisection due to a stab wound,

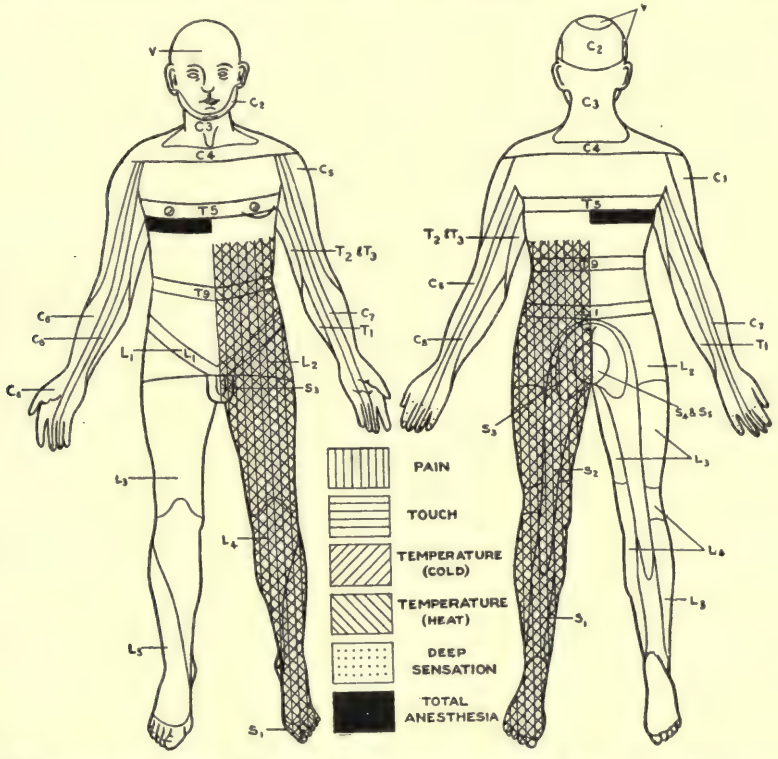

Fig. 202.—Brown-Séquard Syndrome in Lesion of the Sixth Thoracic Segment. On both sides below the cutaneous distribution of T_6 there may be ill-defined areas of tactile anesthesia.

nevertheless, in order to understand that peculiar symptom picture, it is well to consider the symptomatology of exact hemisection—the so-called *Brown-Séquard syndrome.* Let us suppose, for example, that a man is stabbed in the thoracic spine, the knife dividing the right half of the spinal cord between the fifth and sixth thoracic segments. The symptom picture of such a lesion will be as follows: complete paralysis of the right lower extremity, most likely of the flaccid type at first, some possible diminution or even loss of tactile sensation on the right extending up on the trunk to the cutaneous distribution of the fifth thoracic nerves—the chances are that this tactile anesthesia will be neither pro-

found nor permanent—a loss of pressure, position and osseous sense on the right, below the level of the lesion, loss of thermal and pain sense on the left up to a line somewhat lower than the sensory involvement of the opposite side. In addition to the above symptoms there are certain sensory disturbances forming a zone of variable width between the normally innervated skin above and the anesthetic areas below. On the homolateral side this zone consists of a band of total loss of all forms of sensation and is due to the fact that the section cuts a certain number of axons of the posterior root immediately below, or possibly two roots below, before they have had a chance to decussate. On the contralateral side one does not find a zone of complete loss of all sensory function, but rather a zone of hyperesthesia at a level a trifle below the root-zone symptoms of the homolateral side (Fig. 202).

It is well to sound a note of warning against the expectation that these cases will all conform to the given prototype. Two factors should be constantly borne in mind in making the diagnosis of hemicontusion or -laceration of the spinal cord. First, an exact hemisection reaching just to the midanteroposterior diameter of the cord is a very rare occurrence. Usually the injury is not symmetrical and the symptom picture is accordingly confused. Secondly, the question of tactile anesthesia is a most variable one. Reference to the chapter on Physiology will show that tactile impressions may take one of two paths upward—one a direct, the other a crossed tract. It is, therefore, likely that what tactile anesthesia is present in the early hours or days subsequent to the injury may gradually subside and we may picture a condition of assumption on the part of the crossed tract of the tactile function of the homolateral side. The only place where tactile sense is lost with great regularity and permanency is in the cutaneous surface supplied by the nerves of the posterior root sectioned immediately after its entrance into the cord.

Lesions of the Cauda Equina

In any traumatism below the second lumbar vertebra the substance of the spinal cord is not damaged, as this structure ends at about the intervertebral disk between the first and second lumbar vertebrae. Nevertheless, although the cord itself be out of range of injury the same cannot be said for the spinal nerves which here form a great collection completely encircling the conus and running down the spinal canal to the several points of exit. It becomes evident, therefore, that the lower the injury the fewer are the pairs of nerves that may be injured and the more confined is the flaccid paralysis to the lowermost roots of the sacral region.

A fracture-dislocation between the second and third lumbar vertebrae may crush the emerging spinal nerves through the second lumbar inter-

vertebral foramina and also crush all the lumbosacral nerves below the second lumbar in the spinal canal. In such a case there will be a complete flaccid paralysis of the entire lumbosacral plexus with atrophy, loss of reflexes, reactions of degeneration and rectal and bladder incontinence. The sensory symptoms will consist in an absolute loss of all forms of sensation below Poupart's ligaments anteriorly and from the superior edge of the sacrum posteriorly. If the injury spare the second lumbar nerves but involve the third lumbar nerves and those below, there will be the same motor paralysis, but there will be preservation of the cremasteric reflex, and the sensory disturbance will not reach up into the gluteal region behind nor above a straight line at the base of the symphysis pubis at right angles to the long axis of the body anteriorly. With involvement of the fourth lumbar nerves and those below, there will be preservation of function in the psoas, sartorius, iliacus internus, pectineus and adductors with some retention of the knee jerk. The sensory involvement will be a complete loss of all forms of sensation from the knees downward. With a preservation of the fourth lumbar nerves and a loss of all the spinal nerves below them, there will be added to the above a functional activity of the quadriceps femoris, gracilis and obturator externus with complete preservation of the knee jerk. The sensory loss will be confined to the outside of the leg, from the knee downward, and to the entire foot. Where the fifth lumbar nerves are spared and all below involved, the motor disturbance will include the long extensors of the foot and toes, the peroneus longus and brevis, the pyriformis, obturator internus, gemelli, gluteus maximus and all muscle groups below this innervation. The sensory loss is confined to the dorsum of the toes, the plantar surface of the feet and a narrow strip up the back of the legs and the thighs together with a saddle-shaped area on the buttocks. Where the first pair of sacral nerves is preserved and all below are destroyed, the paralysis is of the calf muscles, including the flexors of the foot and toes. The sensory loss is confined to a narrow strip beginning on the posterior aspect of the calf about ten centimeters below the bend of the knee and passing upward, as in the instance mentioned immediately above. In this lesion there is no anesthesia of the feet.

Following a fall down an embankment of twenty-five feet there was transitory paralysis of the lower extremities and sensory disturbance in the distribution of the sacral roots. Distribution of sensory disturbance corresponded to the injury of the second to fifth sacral roots inclusive.

The patient, *aet.* 32 (File No. 1265), was admitted to the University Hospital, January 19, 1906, with a history of having been thrown from his horse four weeks before, falling down an embankment a distance of twenty-five feet. He was unconscious for twenty-four hours, and upon recovery was found to be paralyzed in the left lower limb and partially in the right. Since that time, however, he had

recovered a great deal of power in the right limb and some, but to a less extent, in the left. Since the injury there had always been retention of urine and incontinence of feces.

Sensation of all forms was normal in the left lower limb except in portions later to be described. For temperature, sensation was lost in the circumanal region and in a strip down the posterior aspect of each thigh. Below the knee there was also a strip on the posterior aspect of the leg where sensation for temperature was impaired. Tactile sensation was completely lost in the circumanal region and on the posterior aspect of either thigh, but was entirely normal below the knee. The pain sense was lost in an area which corresponds very closely to that for the disturbance of temperature sense. The area of analgesia extended to from 10 to 12 centimeters on either side of the anus, and from 10 to 12 centimeters below the fourth lumbar vertebra, thence in a triangular zone down the back of each thigh, terminating in a point about 10 centimeters above the popliteal space. This analgesic area affected both sides symmetrically. There was loss of sensation for all forms in the scrotum and penis, but sensation was at least partially preserved in the perineum. The Achilles jerks were absent on both sides and patellar reflexes were exaggerated. Cremasteric reflex was absent. The patient was able to flex and extend fully both right and left lower extremities, to move toes freely, and movement of all the joints seemed unimpaired.

There were no indications for operation and the patient was discharged from the hospital. When last heard from several years later, it was reported that the patient had greatly improved, recovering partial function of the bladder.

Where the second pair of sacral nerves is preserved and all below are injured, the muscles of the perineum are paralyzed and the sensory loss is confined to the saddle-shaped area on the buttocks and perineum. Injury of the fourth and fifth pairs of sacral nerves gives a saddle-shaped area of anesthesia very much more limited in extent than when the third sacral nerves are injured. In all the above cases the upper distribution of the paralysis has been stated and, of course, the distributions below are in all cases understood to be paralyzed if, as in our premises, the destruction of the roots at the indicated level be complete. In destruction of the second sacral roots the power of erection is usually lost. Destruction of the third pair of sacral nerves usually paralyzes the sphincters of the bladder and rectum. It is not necessary for the lesion of the cauda equina to be symmetrical and in such a case one must be prepared to find the picture of inequality in the height of the segmental loss on the two sides.

DIFFERENTIAL DIAGNOSIS OF CORD LESIONS

The differential diagnosis between hemorrhage and contusion involving the spinal cord is often a very difficult, at times impossible, task. Other things being equal, the chief seat of hemorrhagic involvement is the gray matter, whereas in contusion of the spinal cord the injury is likely to be of a transverse type affecting the white matter as well as the gray. Then again, contusion often leads to hemorrhage either primarily

or secondarily, and except in case of careful microscopical examination it would be impossible to state that a given case of contusion of the cord was uncomplicated by hemorrhage. Nevertheless we can say that following contusion, in which hemorrhage is either not present or else is of minor importance, the symptoms follow the injury at once. Also the symptoms, motor and sensory, due to involvement of the white matter of the cord are pronounced. These consist in paralysis or weakness with spasticity and increase in the reflexes whose arcs pass through segments below the injured level. Of course, if the contusion be of sufficient grade, there may be a total abolition of all reflex activity below the level of the lesion. In the case where hemorrhage is the main factor, the paralysis or weakness is not likely to be of so severe a grade at the early stages of the trouble. There is, however, when the hemorrhage is considerable and is being constantly augmented, a progressively greater degree of upper motor neuron paralysis. Usually in these cases a careful examination demonstrates areas of dissociation of sensibility. An important observation in cases of hemorrhage into the substance of the cord is the progressive ascent of the indicated level of involvement. This is due to the passage of the hemorrhage upward in the gray matter, and may cause a change in the sensory topography of several centimeters in a few hours. Although there may be some pain in the case where a hemorrhage is increasing within the substance of the spinal cord, yet we should not expect to find this symptom of such agonizing character as in cases of meningeal hemorrhage.

It is well to call attention to a few points in the differential diagnosis between some of the conditions met in trauma of the spine. The most frequent possibility of error is whether a compression or contusion of the spinal cord is complete or incomplete. As has already been indicated, very often it is impossible to make this differentiation immediately after the injury, on account of the fact that spinal shock, even in cases of slight injury, may give rise to the picture of complete solution of continuity. But after this initial period of shock has passed and we may assume that the symptoms present are the expression of organic change, the total absence of all reflexes below the level of injury, the complete flaccid motor paralysis and the absolute loss of all forms of sensation, speak in favor of the complete lesion, indicating a contusion or laceration of the cord, usually irreparable. As has been emphasized by Bastian and Bruns, the continued loss of the deep reflexes is almost pathognomonic of a complete transverse lesion. In cases of hematorachis the stiffness of the spinal column, as well as the radiating and girdle pains, may cause some difficulty in making the diagnosis between this condition and meningitis. In the latter affection there is either no history of trauma, or if there be, the trauma has occurred some time before the symptoms of irritation. Meningitis is frequently secondary to some other infectious

process and the symptom picture is likely to be characterized by grave, general toxic manifestations; also lumbar puncture is quite conclusive. The hematomyelia, six months or more after the injury, may present a picture similar to syringomyelia or to amyotrophic lateral sclerosis. Amyotrophic lateral sclerosis is always of gradual development and is unaccompanied by any sensory disturbance of an objective nature. In a case previously normal, suffering a spinal trauma, the likelihood is altogether in favor of hematomyelia as against syringomyelia. Of course, the possibility of an unsuspected syringomyelia or gliosis must be acknowledged. In such a case there might be a hemorrhage in the substance of the cord following a trauma. In fact, the area of gliosis might be supposed to offer less resistance to the impact than would normal tissue; but such a condition of affairs would be a rarity.

The greatest difficulty in differential diagnosis will be encountered when we try to determine a possibly organic origin in a case of "railway spine." Careful attention to the condition of the reflexes, with particular reference to the Babinski phenomenon, a meticulous charting of areas of anesthesia of various types, and the avoidance of anything on the part of the examiner which might suggest an expected or possible finding to the patient, will usually determine the organic or functional nature of the condition. A rapid atrophy, which cannot be attributed to disuse, the Babinski sign, the limitation of anesthetic areas to segmental distributions—all of these, particularly when there is an absence of the neurotic temperament and history, speak in favor of an organic lesion. We must always bear in mind the possibility of the presence of hysteria in a patient who has suffered an organic lesion of the spinal cord.

THE TREATMENT OF INJURIES TO THE SPINAL CORD AND MEMBRANES WITH OR WITHOUT FRACTURE OR FRACTURE-DISLOCATION

One of the most difficult surgical topics to deal with in any dogmatic or didactic fashion is the immediate treatment of spinal cord injuries, and by *treatment* I refer specifically to active treatment—that is, operation. To be sure, the problem is reduced to one of great simplicity if the surgeon be affiliated with the ultraconservative wing—which looks upon operation as a useless procedure in such a large percentage of cases that, unless under some exceptional conditions, an exploratory laminectomy is the exception rather than the rule—or, if one become affiliated with the ultraradical group, with which it is the custom rather than the exception to resort to an exploratory laminectomy because of the difficulties and uncertainties of diagnosis. Between the two extremes there is a large field of opportunity for the critical study and analysis of the symp-

tom-complex, a discriminating study of the clinical findings and the determination for or against operation based upon the facts as elicited in the case under consideration. Holding to this as the soundest principle upon which to build, the surgeon has before him a difficult task in the selection of cases for exploration. To cover the ground the various lesions of cord and spine must be taken up systematically, including hematorachis, hematomyelia, dislocations, fractures of the several processes and fracture-dislocations.

Specific Indications.—We must differentiate between hemorrhage without and hemorrhage within the dural sac. While it is conceivable that *hemorrhage without the dural sac* may give rise to symptoms of compression, it is an unusual event; but the mere evidence of compression of gradual onset should, I believe, be recognized as an indication for exploration, and in an occasional case the operator may find the symptoms of compression due to a blood clot, the removal of which is followed by return of function. Such were the circumstances in a case reported by Jonas. The patient thought he could move his legs for a few moments after the accident, so that compression was not instantaneous. However, he soon lost all sensation and motion below the epigastrium and at the operation ten days later, after removal of the laminae of the sixth and seventh thoracic vertebrae, a firm extradural blood clot was found and removed. Sensation and motion practically returned and a year later the patient was able to walk fairly well with a cane.

The management of *hematorachis of subdural origin* is really not so difficult. At least the recognition of the nature and seat of the lesion offers no serious obstacle, if as in many cases there are signs of spinal root irritation, such as stiffness of the neck or truncal spines, lancinating pains in the extremities and girdles of pain and hyperesthesia about the trunk. If these signs of spinal root irritation be followed by those of compression, gradual in onset, not instantaneous, the presence of a subdural hemorrhage, a hematorachis, may be more than suspected and the propriety of an exploratory laminectomy will be determined by the degree of functional disturbance. The complete loss of both motor and sensory function is regarded as a justification for intervention, although preceding this I note the effect of lumbar puncture. I am not unmindful of the fact that in many cases the hemorrhage may be absorbed and the signs of pressure disappear in the course of four weeks and upwards, but one is confronted in the first place with the possibility of permanent damage to the cord substance, and in the other with the possibility of an error in diagnosis. Consequently, I place hematorachis with signs of pressure among the positive indications for an exploratory laminectomy.

Strictly speaking, *hematomyelia,* uncomplicated, and disassociated from any other effect of the injury, such as fracture-dislocation or extramedullary hemorrhage, is not an operable lesion. There may be situ-

ations in which a combination of circumstances may seem to justify an operation, when, for example, a dual lesion may make a positive diagnosis difficult and the operation is purposely exploratory. But in hematomyelia, pure and simple, the nature and distribution of the hemorrhagic lesion are such that surgical intervention will be of no avail. If we call to mind the pathology of hematomyelia, we will remember that the hemorrhagic areas may be multiple, of small dimensions, and may be distributed through several segments of the cord. Therefore, even were it desirable for other reasons, as the relief of pressure, the removal of intramedullary hematoma is not a feasible proposition. The damage to gray matter is almost instantaneous and so much of the cord tissue as may survive the immediate effects of the injury may subsequently be relieved of pressure by at least partial absorption of the clot. Again the most common seat of hematomyelia is in the cervical segments of the cord, and in the majority of fatal cases, death is due to involvement of the phrenic center. Furthermore, associated with the hematomyelia will be almost inevitably a contusion or laceration of the cord, either of which will determine the degree of functional recovery. And again in hematomyelia there is in many cases spontaneous recovery of function to a very considerable degree, so that even without surgical interference, the prognosis compared with that of other traumatic spinal lesions is more hopeful. From whatever angle it may be viewed, pathological or clinical, we are forced to the conclusion that hematomyelia is not a lesion that can be favorably influenced by surgical interference. As a matter of fact, however, the condition is not one that is easy of recognition and the symptoms are frequently masked by an associated contusion or laceration. But in a hypothetical case when the diagnosis is unquestionable and the contusion or laceration insignificant, operative intervention should be regarded as contra-indicated.

Having considered the treatment of hematorachis and hematomyelia, we turn now to the discussion of *contusion and laceration of the cord* and one cannot when dealing with these leave out of consideration the *associated skeletal injuries.* To be sure, there are examples of overstretching of the cord, chiefly in the cervical region where, irrespective of either fracture or dislocation, the damage to the cord may be such as to determine a complete transverse lesion; there are other cases where the cord is damaged by displacement of one or another vertebra which at the time of examination may have been restored to its normal relationship; but in the majority of instances there is, associated with the cord injury, a skeletal deformity, be it a luxation, a fracture of the various processes, or a fracture-dislocation.

We have already discussed, when dealing with *dislocations,* the advantages of open reduction, and have taken the position that, provided the facilities for performing a laminectomy under every safeguard are at

hand, the open method of reduction should be adopted as safer than the closed method. In reviewing the treatment of *fracture of the several processes*—spinous, transverse—or of the laminae, we outline the conditions under which surgical interference was indicated. Thus we recommended an operation in cases of (1) fracture of the laminae with cord or root involvement and with little evidence of spontaneous improvement within the first week, and (2) fracture of the transverse or spinous processes when continued pain and disability suggest the presence of an ununited fragment or exuberant callus.

What should be our attitude toward *fracture-dislocations?* At the outset we must admit that in the majority of cases the cord is irreparably damaged at the time of the accident, but there remain a few cases in which the arrest of cord function is due to an acute compression as the cord is stretched over the sharp margin of the projecting fragment and to edema and hemorrhage. This picture will be recalled vividly by those whose operative experience has included many cases of spinal injuries. Be the chance of recovery ever so small, I should not hesitate in these cases to recommend operative intervention at the earliest possible moment, irrespective of whether the symptoms indicate a complete or partial lesion, for the purpose of reducing the deformity if possible, and if not, of removing the sharp edge of the displaced fragment and thus relieving the cord of pressure. The following case may be cited as one in which there was considerable restoration of function following laminectomy:

Fracture-dislocation of the twelfth thoracic and first lumbar vertebrae, with complete loss of power and partial disturbance of sensation. Following laminectomy sensation was restored in the course of the next six months and power was regained in the thighs but not in the legs.

The patient, *aet.* 50 (File No. 639), was admitted to the University Hospital Dec. 21, 1902, with the history of having been injured four days prior to his admission. Seated upon a coal wagon, while driving under a bridge, he was doubled up like a jack-knife. He was unconscious for several minutes after the injury and upon recovery of consciousness he was unable to move the lower extremities, and complained of pain in the lower thoracic region of the spine. At that time it was recorded that there was complete loss of motion and sensation below the level of the umbilicus, above which there was an area of hyperesthesia. There was incontinence of feces and retention of urine to overflow.

Examination upon admission to the hospital revealed the following facts: There was an area of ecchymosis in the region of the twelfth thoracic and first lumbar vertebrae, and pressure over the spinous processes elicited tenderness. Sensation of all forms was retained over the anterior surface of the right thigh but imperfectly so on the lateral and posterior aspects, except in the distribution of the small sciatic nerve, where sensation was entirely lost. Sensation to touch was retained in a band around the extremity above and below the knee, but in this zone pain and temperature sense were lost or greatly impaired. Below this point there

was complete anesthesia, except in the lower third of the leg along the surface of the tibia. In the left lower extremity there was complete anesthesia in the distribution of the small sciatic nerve and below the knee sensation was retained, though imperfectly, except in the region of the external malleolus. There was sensation for all forms on the cutaneous surface of the penis and scrotum. Above the level of Poupart's ligament on both sides sensation was not disturbed. The abdominal reflexes were present; the cremasteric, patellar tendon, tendo Achillis and Babinski were absent. With the exception of slight contractility of the adductor magnus and quadriceps extensor of the left thigh, motion of the thigh was lost in both lower extremities.

Laminectomy was performed Dec. 23, 1902, revealing a fracture-dislocation at the junction of the thoracic and lumbar spine and pressure upon the cord.

Jan. 8, 1903.—The distribution of the sensory disturbance of the lower extremities had not changed materially, except that in the area in which sensation was not entirely lost it was more acute, and all forms of sensation were partially restored to the penis and scrotum.

April 20, 1903.—The patient was able to flex both thighs on the abdomen and to adduct the left thigh. There was as yet no return of motion below the knees and the patient complained at frequent intervals of shooting pains in the legs.

Two months later sensation was restored in both lower extremities; movements of the thighs improved, but as yet and until the time of the patient's discharge from the hospital there had been no return of motion below the knees.

Incontinence of urine and feces was still present.

Having given certain specific indications for operation based chiefly upon the presence or absence of direct compression of the cord from hemorrhage, from a displaced vertebra or fragment thereof, let us view this question of operation from another angle, that is, from the **clinical syndrome**. Generally speaking, these injuries of the spine and cord are roughly divided into two classes: those with symptoms of a *complete transverse lesion,* and those with symptoms of a *partial lesion.* There is a prevailing sentiment that a complete transverse lesion is in itself a positive contra-indication of operation. To maintain this attitude one must assume that the symptoms of a complete transverse lesion invariably indicate an irreparable damage to the cord. Clinical experience, however, does not bear this out. There are many examples of recovery of function to a greater or less degree where immediately after the injury there was complete loss of motion and sensation and abolition of all reflexes. We must reckon, therefore, with the possibility of error in the interpretation of symptoms when we attempt a prognosis or discuss the arguments for or against operation, and I have come to disregard the clinical picture of a complete transverse lesion *per se* as a contra-indication to operation.

In opposition to this attitude, one might contend that any doubt as to whether the cord is damaged irreparably will be dispelled if one but wait a few days or longer to see whether there be resumption of function. To accept this plan as a solution of the problem is not consistent with the view which I hold—that if operation is to be performed at all, it should be done at the earliest possible moment.

This naturally leads to the discussion of the relative merits of the *immediate* or the *later operation.* Statistics have been quoted *in extenso* in favor of one or the other procedures, but to me these statistics are not to be accepted as a basis for settlement because of this fact: that the cases upon which the late operation has been performed are those which have survived the immediate effects of the injury and, therefore, comprise a more favorable group for operative intervention, at least from the standpoint of mortality. The susceptibility of the nervous tissue to the effect of trauma, be it the direct compression of blood clot, of bony fragment, edema, or traumatic effusion, is such that unless promptly relieved recovery of function is doubtful. Upon these two factors—namely, the element of uncertainty as to the extent of the injury and the damaging effect of compression upon the viability of the cord—must the decision rest in favor of early or late operation. Much has been said and written as to the relative safety of early and late operation. The late operation is said to be attended with a lower mortality, and for this reason should be given preference. I believe, however, that the risk of early or immediate operation has been overestimated, if my own experience be any criterion, since in a series of twenty operations there has been but one fatality. This occurred in a fracture of the fifth cervical vertebra and the patient succumbed on the fifth day, not because of the operation, but from involvement of the phrenic center.

In a series of 717 cases collected from various sources (Table VII), I have tabulated the results according to whether an operation was or was not performed.

TABLE VII

Of the total number there were 442 (61.6 per cent) deaths	202 (28.1 per cent) with operation
	240 (33.5 per cent) without operation
Of the total number there were 275 (38.4 per cent) survivals	77 (10.8 per cent) recoveries:
	68 (9.5 per cent) with operation
	9 (1.3 per cent) without operation
	124 (17.3 per cent) improved:
	101 (14.1 per cent) with operation
	23 (3.2 per cent) without operation
	74 (10.3 per cent) unimproved:
	65 (9.0 per cent) with operation
	9 (1.3 per cent) without operation

From this array of figures, it is evident that while the mortality was high both with and without operations, the percentage of recoveries or improvement was larger in the operative than in the non-operative series.

Bearing upon this question it may not be amiss to call attention to the fact that, with the addition of measures of safety in recent years,

the mortality of operations upon the spinal cord has been materially reduced. Thus, if we turn to the tabulation of a series of cases operated upon prior to 1911 and a series operated upon between 1911 and 1915 (Table VIII), one sees a striking reduction in the mortality rate. Prior to 1911, the operative mortality was 20 per cent and from 1911 to 1915 less than 7 per cent.

TABLE VIII

A Table Comparing the Results of a Series of 499 Cases Treated Prior to 1911 and a Series of 314 Cases Treated Between 1911 and 1915

	Prior to 1911					1911 to 1915				
	Immediate Operation	Late Operation	No Operation	Total	Percentage	Immediate Operation	Late Operation	No Operation	Total	Percentage
Recovery	8	24	9	41	8.2	4	4	51	59	18.8
Improved	12	40	23	75	15.1	5	30	86	121	38.6
Unimproved	7	28	9	44	8.8	5	3	18	26	8.3
Death	64	35	240	339	67.9	14	8	63	85	26.8
Not stated	0	0	0	0	0	0	2	21	23	7.5
Total	91	127	281	499	100.0	28	47	239	314	100.0

As already stated, we cannot forecast the extent to which function may be recovered and the satisfactory results that occasionally follow operation form a powerful argument in favor of the radical as compared with conservative plans of treatment. In this connection the following case is of interest:

Fracture of the first, second and third lumbar vertebrae. Partial lesion of the cord. Laminectomy. Almost complete recovery of motion and function of the right lower extremity; partial recovery of the left. Patient was able to walk unsupported when discharged from the hospital.

The patient, *aet.* 7 (File No. 273), was admitted to the University Hospital November 11, 1901, with the history of having caught his head and neck between the spokes of a wagon wheel. The physical examination revealed that both pupils were equal and reacted to light and accommodation. Apart from slight subconjunctival hemorrhage in both eyes there were no ocular phenomena. In the lumbar region the spinous processes of the second and third lumbar vertebrae were displaced to the left of the median line and formed the apex of a kyphosis; pressure upon it elicited some tenderness. There was, however, no crepitus or preternatural mobility. There was no involvement of motion or sensation in the upper extremities, except in so far as movements of the left arm were affected by a fracture of the humerus. Sensation was preserved in the back and chest and abdomen and there was no incontinence of urine or feces. The patient was unable, upon admission,

to move either lower extremity, excepting that he could flex the toes. Three days later it was noticed that he was able to rotate the leg slightly inward but not outward. Sensation was undisturbed. In response to electrical stimulation there was but slight contraction of the muscles of the right thigh and none in the gluteal region and the extensor or flexor muscles of the leg. There was slight reaction when the electrode was applied to the plantar surface. In the right lower extremities the conditions were practically the same, except that flexion and extension of the toes were feeble. There were no patellar tendon reflexes, no plantar, no Achilles or Babinski reflexes. The cremasteric reflex was present and normal.

Eleven days after admission there was no response to a strong faradic current in the lower extremities, except in the muscles of the calf, which responded slightly. A day or two later it was observed that patient was able to rotate inward both right and left lower extremity, but only to a slight degree. Owing to the fact that the case was evidently not one of complete transverse lesion and that there was little tendency to restoration of function since the patient's admission to the hospital, an exploratory laminectomy seemed indicated. Accordingly, on November 23, under ether anesthesia, I explored the lumbar region, removing the spinous processes and laminae of the second and third lumbar vertebrae, which, together with the first, were the seat of fracture. There was no apparent point of compression and so far as naked eye appearances were concerned the cord itself did not seem to have been damaged.

The day after the operation the patient was able to flex the left thigh on the abdomen, and the next day he could turn himself over in bed without assistance. Power of the flexor muscles of the thigh had improved considerably. A week later he was able to flex both thighs on the abdomen but could not extend them, though five days after this there was slight restoration of function in the extensor quadriceps. By the third week the extensor, peroneal and flexor groups of the right leg responded slightly to the faradic current. There was slight response also in the corresponding muscles of the left leg, although to a less degree. Between this time and that of his discharge from the hospital ten weeks later the following notes were made: January 3rd, internal and external rotation of the right lower extremity much improved and of the left to a less degree. January 17th, for the first time noticed that the patient could extend the leg upon the thigh; in fact, all movements of the lower extremities, excepting those of the extensor quadriceps and the gluteal muscles were present. The patient was receiving massage daily and electrical treatment twice a week. January 31st, the patient was strong enough to attend the hospital gymnasium; daily massage was continued; he was stronger and all movements of the leg and thigh were increasing. February 15th, he was able to stand by the side of the bed and could walk if supported. Power was returning more rapidly to the right leg than to the left. March 18th, he was walking about the wards with the aid of crutches. There was still more power in the right than in the left leg.

The patient remained in the hospital until the 15th of May, at which time he had been provided with a brace which gave him considerable comfort and without assistance he was able to walk the entire length of the ward, although the left leg was still weak and there was a tendency to drag the left toes.

Operative Procedures.—In considering the indications for operations in injuries of the spine and cord one must not overlook the benefit that may be derived weeks or months after the original injury. The disturbance of function in these cases may be only partial; there may be weakness of one upper or lower extremity; there may be disturbance of sensation in the

form of hypesthesia or hyperesthesia, or there may be root pains when the posterior roots are involved either by fibrous tissue or by a displaced fragment. An *exploratory laminectomy* in these cases may reveal definite pressure upon the cord from a displaced fragment of a fractured lamina with definite angulation of the cord as in fracture-dislocation. The removal of three or four laminae will relieve the pressure upon the cord and be followed by more or less improvement. If there be pressure on the cord by the margin of the displaced vertebral body the projecting edge of the vertebra should be removed.

There is one more aspect of the operative treatment of fractures that I am tempted to introduce in this discussion—that is, the possible influence of a *decompressive laminectomy* upon injuries to the spinal cord. There are many instances in which an inspection of the cord on the operating table fails to reveal any outward evidence of injury. Whatever the lesion may be it has been the result of a momentary compression or stretching of the cord coincident with the injury. At all events there has not been any visible break in the continuity of the cord tracts. Having observed unexpected improvement following exploratory laminectomy in some cases, I wondered whether it were possible that a decompressive laminectomy could influence the effects of the cord lesion. I recalled to mind the favorable influence of decompressive laminectomy upon lesions of the cord of other than traumatic origin, including meningomyelitis and some undetermined lesions, and by a process of analogy the thought arose that a decompressive laminectomy might in some way, yet to be explained, encourage resolution of a traumatic cord lesion. The fact remains that in my clinical experience there are records of function recovered that without operation would not have been anticipated.

A dual lesion of the spine. A fracture-dislocation of the third thoracic and fracture of the twelfth thoracic and first lumbar vertebrae with complete disability. Following laminectomy, the patient gradually recovered function of bladder and rectum; restoration of sensation was almost complete, and with the aid of crutches the patient could walk a mile.

The patient, a young girl, *aet.* 17 (File 32079), was admitted to the University Hospital January 6, 1916, with the history that on December 22, 1915, she had been caught between the floor of a moving elevator and the lintel of the door of the elevator shaft. For twelve hours she was unconscious and for eight hours pulseless. There was bleeding from the nose and both ears and ecchymosis of the conjunctivae. Examination after restoration of consciousness showed that there was no involvement of any of the cranial nerves. There was a slight weakness of the muscles of the left forearm and the grip of the left hand was weak. There was also some slight weakness in the grip of the right hand but not so pronounced as on the left. The biceps tendon jerk on the left was diminished, but on the right, normal. Sensation in the upper extremities was normal.

There was practically no voluntary motion in either lower extremity. Sensory examination of the thorax and abdomen, both anteriorly and posteriorly, demonstrated good perception of all forms of stimuli. It was noted, however, that above the ninth costal cartilage there was possibly a band of slight hyperesthesia. With the exception of a small area of slight diminution of tactile sensation over the right hip, the lower extremities had preservation of all forms of sensation throughout. The knee jerks were present and normal, but Babinski reflex was present on the left and very slightly present on the right. There was no ankle clonus on either side. She had complete incontinence of bladder and rectum. The x-ray examination demonstrated a fracture-dislocation of the third thoracic vertebra and a fracture of the twelfth thoracic and first lumbar vertebrae.

There was a most interesting observation made before her admission to the hospital, to wit: she had complete loss of reflexes and motion in the lower limbs for three days subsequent to the accident. Four days after the accident she developed pains in the lower limbs more severe in the right than in the left. There was "complete anesthesia" of the body below the level of the eighth rib. After four days the reflexes and sensation returned.

Laminectomy was performed on January 8, 1916, the spinous process and laminae of the third thoracic vertebra being removed. There was no visible abnormality of the spinal cord detected and the cerebrospinal fluid was clear. The lower trauma was not explored.

On January tenth patient complained of inability to move her arms. From this time on there was a steady improvement in the condition of the upper extremities, but the lower limbs gradually became spastic with increased reflexes and pronounced Babinski phenomenon on each side. The lower limbs were often held in a position of extreme abduction, which, however, the patient was able to correct. Gradually a partial control of bladder and rectum returned. There were at times records made of slight obtunding of one or another form of sensation in the lower limbs; but these observations were never quite definite enough to chart and usually were more of a delay in transmission or a lack of accuity than a positive loss.

On March 14, 1916, I noted, in a letter to her family physician, that the sensory disturbance had very largely disappeared and that she was recovering voluntary motion in her lower limbs, had regained complete control of the rectum, and could control the bladder for three hours at a time. Her after-treatment was along hydrotherapeutic lines with massage and electricity. She was discharged from the hospital July 1, 1916 (Fig. 203, A and B).

The operative procedure after the removal of the laminae will, of course, depend upon the character of the skeletal injury and of the cord lesion. Where there is direct pressure either on cord or roots from a displaced lamina or transverse process the method of procedure is clearly indicated: the fragments should be elevated, and, if not easily secured in place, should be removed. Where there is a marked deviation of the vertebral canal from fracture-dislocation with the characteristic stretching, compression or laceration of the cord over the sharp edge of the displaced fragment, measures must be adopted to reduce the dislocation and restore the alignment of the canal. This must be done, of course, without inflicting additional trauma upon the cord itself. With the aid of two assistants extension and counterextension are made from the head and feet of the patient while the operator makes pressure directly back-

A B

FIG. 203.—DOUBLE FRACTURE OF THE SPINAL COLUMN. (University Hospital, File No. 32079.)

A, Partial recovery following laminectomy. With the aid of crutches and a suitable brace the patient is able to walk and has regained control of the bladder and rectum. *B*, Eighteen months later patient has dispensed with one crutch and the brace of one leg.

wards upon the displaced fragment. In some instances reduction is accomplished without difficulty; in others, repeated efforts may fail altogether or in part. A clot either above or beneath the dura should, of course, be removed.

There are still two procedures which should not be omitted in discussing the operative treatment of fractures and injuries to the cord—namely, *chordotomy* and *cord suture.* We have discussed somewhat at length the experimental data upon which was founded the recommendation that a linear incision of the cord should be made as soon as possible after an injury (*see* p. 398). From these experimental observations there remains no doubt that when practiced immediately after an injury a median posterior incision in the cord has a most beneficial influence even up to the point of restoring complete function in a case in which there was every clinical evidence of complete transverse lesion. There have been up to the present time no clinical experiences in any way comparable with the experimental evidence, because it is not practicable, as in the experimental laboratory, to operate and relieve tension immediately after the injury. It was claimed by Allen for the *rationale* of this method that from the incision serum and blood escaped, which, when pent up in the cord itself, caused sufficient pressure to destroy the vitality of the cord substance.

I would like to be able to finish the discussion of traumatic lesions of the cord without the consideration of *myelorrhaphy;* but the matter is of such importance, not only from the clinical but from the scientific aspect, that I could not very well pass the subject by unmentioned. We are confronted with a very unusual situation in which, on the one hand, is a series of cases almost insignificant, to be sure, as compared with the total number of cord injuries, and on the other, a concise statement based upon repeated investigations, which sides cannot be made to harmonize. Briefly stated, there are upon record seven cases in which, after complete or almost complete severance of the cord from one cause or another, the divided ends were sutured, and of this number there was partial restoration of function in five (Estes, Briggs, Stewart and Harte, Shirres, Fontan) and no improvement in two (Fowler, Solieri). The accumulated evidence of years of investigation along lines of nerve tract regeneration, both peripheral and central, looks with absolute skepticism upon the possibility of regeneration of the cord, and explains the clinical results that are said to follow suture of the cord in various ways which we shall consider later.

I will herewith present the clinical evidence in brief abstracts of the seven cases of cord suture.

Case 1.—Operator, Estes; 1889. The operator made a complete section of a disintegrated cord at the level of the first lumbar vertebra, removed about 2 cm.

of the cord, squared off the ends, and approximated them with catgut sutures. The operation was performed ten days after the injury, and it is reported that the cord was "lacerated entirely through," and in the report made twenty-one years after the operation it is said that "the man was considerably improved as regards the trophic and sensory disturbances but had not regained the use of his lower limbs." He subsequently died of an infection of the urinary tract.

(In addition to the above case Estes reports one in which he exsected more than one-half the thickness of the cord in the lower thoracic region, leaving the anterior columns only intact. The ends of the lateral and posterior columns were drawn together by catgut sutures. Following the operation, sensory and trophic paralysis improved almost immediately. The patient, a 19-year-old boy, finally recovered the use of his left lower extremity and of the flexors of the right extremity, so that with the aid of a brace on the weaker side he could walk with comparative ease. The sphincters had almost entirely recovered. On last examination the reflexes, with the exception of the cremasteric reflex, had not returned; the right lower extremity was almost completely paralyzed, while the left had a considerable range of motion. There was no sensation in the right lower extremity or below the upper fifth of the thigh or in the left lower extremity below the lower third of the leg. This young man has been examined two or three times in the last ten years. The reflexes and sensory functions are almost completely restored, sphincteric function quite reëstablished and he is able by the use of braces to work as a stationary derrick man.)

Case 2.—In 1898, Briggs (quoted by Krause) operated upon a boy of seventeen, three weeks after fracture at the level of the tenth thoracic vertebra with complete division of the cord. Both ends of the cord were freshened and approximated with catgut sutures. The functions of the bladder and muscles of the extremities returned very gradually.

Case 3.—Stewart and Harte; 1902. The patient sustained a gunshot wound in the thoracic region. There was complete loss of motion and of sensation below the level of the tenth thoracic vertebra behind and about 2 cm. above the umbilicus in front. Above the zone of anesthesia there was a band of hyperesthesia to the level of the ensiform cartilage. The superficial and deep reflexes were lost. The picture, therefore, was symptomatically one of a complete transverse lesion. The operation was performed three hours after the accident and the cord was reported as completely severed by the bullet. After removing several loose fragments of bone which lay between the divided ends of the cord, separated by about 2 cm., the divided ends were approximated with three chromic catgut sutures. Sixteen months after the accident there was considerable improvement both in motion and in sensation. The patient was able to execute various movements of the toes and legs, could stand with one hand resting on the back of a chair and move from bed to chair, unaided, by a sliding motion. There was partial control over bladder and rectum and partial restoration of sensation as to touch, temperature and pain, in previously anesthetic areas.

Case 4.—Operator, Fowler; 1905. The case was one of gunshot wound at the level of the eleventh thoracic vertebra. The patient, a male, *aet.* 18, had complete paraplegia with paralysis of both bladder and rectum; loss of sensation up to a point midway between the symphysis and umbilicus. The reflexes were abolished. Eleven days after the injury the spinal canal was opened, the cord found to be entirely severed, the two ends separated by the bullet which lay between. The segments were approximated with sutures, and twenty-six months after the injury it was reported that there had been no return of voluntary motion. The patient was able to stand, if supported by the hands, with the aid of an apparatus. Bladder and rectal control had not returned; sensation in the affected territory had not

returned. Failure to recover function has been attributed by the operator to the fact that too much time intervened between the day of injury and the day of suture.

Case 5.—Operator, Shirres; 1905. Again we have a case in which the injury of the cord followed a fracture-dislocation in the region of the ninth and tenth thoracic vertebrae. The patient, *aet.* 48, presented a typical picture of complete transverse lesion, with absolute loss of motion, sensation and reflexes. As there was no return of function, an operation was performed eleven months after the injury. The operator interposed a segment of a dog's spinal cord 7.5 cm. long between the divided ends of the cord. The segments were united to one another by sutures through the pia-arachnoid membrane. The operator reported a gradual return of sensation in the lower extremities, bladder and rectum and a certain amount of tone in the flexor muscles of the thigh and leg. The patient died two and one-half months after the accident from a pyonephrosis. The injured section of the cord was removed at autopsy and the following notes entered: The dura and tissue at the site of the grafting segment showed a mass of minute myeline sheaths of nerve fiber which lay closely adherent to the dura, and when traced upward and downward united with the segments of the cord above and below, demonstrating the fact that regeneration of the axons of the spinal neurons had taken place to a limited extent.

Case 6.—Operator, Solieri; 1908. This is a gunshot wound with fracture of the cord at the level of the third thoracic vertebra. The operator approximated the divided ends of the cord in a male patient, *aet.* 36. Sixteen hours after the injury the cord was exposed, found to be completely severed, the ends separated by a distance of 2.5 cm. The divided ends of the cord were approximated with sutures, and the wound healed three months after the operation. The patient died without recovery of function. The injured section of the cord was removed at autopsy and the divided ends were found to be joined by a bridge of connective tissue in which there was not the slightest suggestion of nerve tissue.

Case 7.—Operator, Fontan; 1909. The injury to the cord in this case was the result of a fracture at the level of the eleventh and twelfth thoracic segments. The case was one of complete transverse lesion. The cord was said to be completely severed at the site of fracture and the approximation of severed ends with sutures was accomplished with difficulty and only after a plastic operation upon the dura. Four and one-half years after the operation paresis of bladder and rectum had entirely disappeared. The patient's general condition was excellent, but so far as motion and sensation were concerned, there had been no improvement. There was no doubt in the mind of the operator that the cord was completely severed.

When discussing the possibilities of *cord regeneration,* we are confronted with an array of contradictory facts based both upon experimental and clinical evidence. On the one hand, there is the work of von Strobe, Bar and Dawson and Marshall (referred to by Krause), who showed regeneration of the fibers of the posterior roots after severance between the spinal ganglia and the cord. In their experimental study of regeneration of the posterior roots, Spiller and the writer carried out a series of operations in which the posterior roots were divided and immediately approximated with fine silk suture. The manipulations were carried out as delicately as possible, and the conditions for reunion were most favorable. Several months after the operation, the specimens were removed and subjected to a critical histological study. Degeneration of the roots was

found to be complete and no young nerve fibers could be seen anywhere. There was no evidence whatsoever of regeneration, although ten months had elapsed since the operation, and it may be assumed that regeneration would not have occurred even had the specimen been removed for examination at a later date. There are the experiments of Trendelenburg, who failed to obtain regeneration after section and suture of the spinal cord. The examination of the specimens revealed a mass of cicatricial tissue in the gap between the retracted segments. Reference might be made to the experiments of Sacki and Schmaus, who found newly formed nerve fibers following the course of the blood vessels. These fibers were few in number, limited to a small area, and as they did not penetrate the scar tissue, restoration of function by this means was impossible. The nerve fibers were chiefly, if not entirely, of the peripheral type and, having neurilemma sheaths, probably did not originate within the cord. In their experiments upon animals, Henle and Mikulicz (referred to by Solieri) were unable to keep in apposition the ends of the divided cord. Thus all the experimental evidence including that upon the posterior roots, which in their physiological activity are analogous to the spinal cord, points unquestionably to the inability of the cord to regenerate itself. This has been attributed to a fundamental obstacle in that the structures involved are devoid of the neurilemma sheaths, which by many are supposed to play so essential a part in nerve regeneration. An explanation has been offered to account for the failure of regeneration after cord suture which attributes the failure to the injury, to the blood supply of the affected parts on the one hand, and on the other, to the formation of a cicatrix which in itself serves as a barrier through which regenerated nerve fibers cannot pass. There may be technical difficulties in holding the divided ends of the cord in juxtaposition, but the explanation may be looked for in physiopathological processes very much more fundamental.

To account for the restoration of function that has been recorded in the few cases, Fowler suggests that uninjured portions of the cord in contact with the dura may have been overlooked; or that recovery of function may have resulted from anastomosis through the medium of branches of adjacent normal trunks having their origin respectively above and below the lesion. This explanation assumes a relative limitation of the ascending degenerative processes in the cord itself, whereby nerve trunks there given off may be assured of continued innervation.

Spiller suggests that recovery after apparent transverse lesion may be explained on the ground of a compression myelitis. After it has been relieved and the edema subsides, restoration of function may be attributed to the vicarious action of fibers that were not destroyed. Despite clinical evidence he is of the opinion that regeneration of the cord is impossible.

Explanation for the recovery of function in apparently complete trans-

verse lesions is to be found in the resumption of function of some overlooked fibers which did not undergo degeneration. The arrest of function coincident with the injury was of transitory character, and as function was resumed improvement to a limited degree was observed. It would seem impossible with any degree of scientific accuracy to correlate the disputed facts either clinically or experimentally. In both instances the evidence is overwhelmingly against the possibility of cord regeneration and there must be additional investigation and further clinical evidence before one can accept unreservedly the fact that cord regeneration is within the range of possibility.

It is not enough that we are confronted with statements that there has been a return of sensation or that paralysis of muscles innervated from segments below the level of injury has given way to restoration of function. The burden of proof is so overwhelmingly on the operator that any such statements may well be set aside unless there be a detailed description of his technic and findings in the examination for muscular function and the various types of sensation. Likewise, the bald statement that there is a disappearance of the paralysis of the bladder and rectum is not sufficient unless it be made perfectly clear that the restoration is restoration with complete voluntary control of the viscus in question. The implantation of a segment of a peripheral nerve or of a section of spinal cord from a lower animal does not deserve consideration.

FRACTURES OF THE VERTEBRAE WITHOUT CORD SYMPTOMS

Among those of the profession who have not given the matter very much thought or attention the opinion prevails that fracture of the vertebra implies more or less paralysis; in other words, they consider that fractures of the spine never occur without a lesion of the cord. This, however, is far from the truth, and unquestionably there can be, more or less frequently, as has been brought to our attention, cases in which the roentgenogram shows the presence of a fracture of one or more vertebrae absolutely without any evidence of lesions of the cord. Recently a patient was brought to me who had fallen headlong downstairs and sustained a fracture of the bodies of the third and fourth cervical vertebrae, but there was no evidence of any injury to the cord. The lower extremities, bladder and rectum were not at all involved, and while there were some sensory disturbances in the upper extremities, these were readily accounted for by injury to the roots. The diagnosis of fracture without cord symptoms is not difficult. As a rule, there is tenderness on pressure over the spinous processes of the injured vertebrae; and usually deformity, such as a kyphosis, which may present a rounded curve or a sharp knuckle.

The extent of the lesion and the degree of displacement will be revealed by the roentgenogram.

In March, 1913, there was brought to my attention a case of fracture of the lumbar vertebrae without cord symptoms.

The patient, a man, *aet.* 30 (File No. 38554), while working in a coal mine was struck in the lumbar region by a mass of falling coal. The accident happened August 7, 1911. He was kept in bed for about two months, although during this time he had little pain and his attending physician reported to me that there was

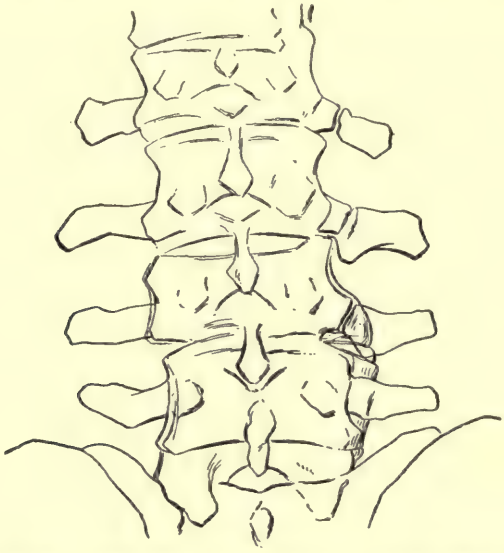

FIG. 204.—DRAWING FROM ROENTGENOGRAM SHOWING A FRACTURE OF THE TRANSVERSE PROCESSES OF THE SECOND, THIRD, AND FOURTH LUMBAR VERTEBRAE. (University Hospital, File No. 38554.)

no loss of reflexes, motion or sensation. He was able at the expiration of this time to get about very well and resumed his work. Some six months after the injury the patient began to complain suddenly of a severe throbbing headache, with pain radiating down the back; at times the pain was intense, and was accompanied by tenderness on palpation over the entire lumbar region. The attending physician was unable to interpret the symptoms, but found that the withdrawal of cerebrospinal fluid by lumbar puncture gave almost immediate relief. The patient was sent to the University Hospital on March 8, 1913, for an investigation into the cause of his headache and incidentally for the repair of hernia. The roentgen ray examination of the spinal column revealed a fracture of the transverse processes of the second, third and fourth lumbar vertebrae and a fracture-dislocation of the fourth lumbar vertebra (Fig. 204). A letter to the physician in attendance at the time of the accident brought us the facts as above recorded. An examination of the patient failed to discover any evidence of motor or sensory disturbance. The cerebrospinal pressure was recorded as 22 mm. Hg, but the serological examination was negative. The relationship between the headaches and the spinal injury was not determined. Certainly the increased pressure of the cerebrospinal fluid,

which might readily have caused the headaches could not be attributed to the spinal injury.

Through personal communication, notes of a case of fracture of the first lumbar vertebra without cord symptoms were brought to my attention by Dr. Francis O. Allen, Jr.

His patient, an insane woman, 40 years of age, on June 18, 1915, fell from a second story window, falling on soft earth, striking first on her feet and then on her buttocks. She got up, ran some distance, was overtaken, brought back, and

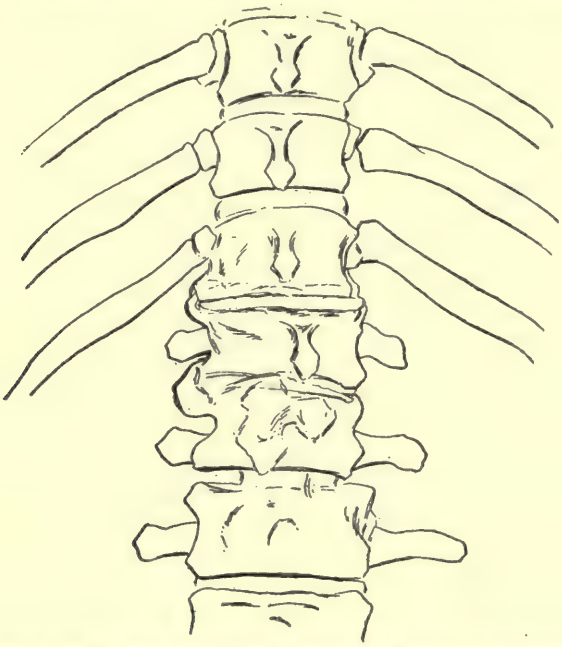

FIG. 205—DRAWING FROM ROENTGENOGRAM SHOWING A FRACTURE-DISLOCATION OF THE FIRST LUMBAR VERTEBRA. (Allen.)

on examination two hours later, there was a distinct kyphosis, with marked swelling of the soft parts in the lumbar region. There was localized tenderness and pain on motion, but no paralysis. A skiagram taken the next day showed a fracture-dislocation of the first lumbar vertebra (Fig. 205). On account of her mental condition and the absence of signs of injury to the cord, it was thought inadvisable and unnecessary to attempt any form of fixation treatment. No apparatus or restraint of any kind was used. Her mental condition improved so much in the next few months that she was allowed to return home. January 17, 1916, six months after the injury, she was again examined. At this time she was working hard in a bakery and complained only of slight pain in the back and of her back being tired after a day's work. There were no cord symptoms. There was a definite small kyphosis with evidence of ankylosis at the thoracicolumbar junction. A skiagram taken at this time showed the consolidation of the first lumbar to the adjacent vertebrae.

PHYSICAL CARE OF SPINAL INJURIES

Regarding the care of the patient surviving the immediate effects of an injury to the spinal cord, attention is required principally for the prevention of bed sores, for protection of the urinary tract against secondary infection, and for the prevention of additional damage to the cord by greater displacement of the fragments. The prevention of decubitus requires the use of an air or water mattress, the use of cotton or pneumatic rings at those points where the skin is subjected to greatest pressure, beneath the os calcis, the head of the fibula, the internal condyle of the humerus, the scapula and the promontory of the sacrum. The bed linen must be protected from soiling with excreta. The skin requires scrupulous care; gentle friction with alcohol, particularly in the region of the sacrum at least four times in the twenty-four hours, to be followed by the application of stearate of zinc powder. When the dusky discoloration of the skin forecasts threatened necrosis, the friction baths should be given more frequently, greater precaution adopted to dissipate pressure, and balsam of Peru applied to the surface. In the majority of instances if the precautionary measures be adopted at the outset and conscientiously continued decubitus will be prevented.

Of greater significance, however, is the probability of infection of the bladder, since sooner or later a cystitis will be followed by an ascending infection, pyelitis, pyonephrosis and death. From the beginning, hexamethylenamin should be given and continued until the reaction of the urine becomes alkaline, when it is replaced with acid benzoate of soda. Rigid asepsis should be observed in the early days of catheterization and if there be retention a suprapubic fistula should be established for drainage and should replace either repeated or permanent catheterization. If, however, the bladder should empty itself by overflow, the greatest protection against infection is afforded and the necessity for either catheterization or suprapubic drainage no longer exists. Despite every precaution, particularly in the complete transverse lesion, cystitis may develop and the bladder must be gently irrigated—never to the point of overdistention—with a warm boric acid or permanganate of potassium (1:10,000) solution, at intervals of two or three days, according to the amount of mucopurulent accumulation. The protection of the cord from consecutive injuries is not to be omitted. In injuries both of the cervical and thoracicolumbar regions there have been many instances, where, for one reason or another, the paralysis has increased. More frequently is this the case in injuries of the cervical spine. For example, in one case a fatal attack of respiratory embarrassment followed on turning the patient on his side. But even in weeks or months after the injury, when, because of the absence of significant

symptoms, the exact nature of the injury was not recognized and no fixation apparatus prescribed, sudden paralysis and respiratory failure followed compression of the cord. For these reasons, therefore, appropriate appliances should be employed, not only while the patient is bedridden, but after the case becomes an ambulant one. Extension applied to the head, counterextension by elevation of the head of the bed and sand bags placed on either side of the head, should be considered as indispensable and imperative. Later, should the case become ambulant, a suitable brace should be constructed to support the head and secure immobilization of the cervical spine for at least six months. At the expiration of this time it may be reasonably assumed that by ligamentous repair and consolidation of the fragments accessory means of support may be discarded. In fracture of the thoracicolumbar segment without cord symptoms an attempt may be made to correct any displacement by the application of pads beneath the lower fragment. By the aid of gravity the normal curve may be slowly restored and the persistence of pain or muscle spasm may be averted. The patient should be kept recumbent for four weeks and then allowed to get up only after a plaster jacket or brace has been provided. This should be worn for at least six months.

There are occasions in which, as a residuum of the injury, patients complain of more or less weakness of the spine and feel unable to return to their occupations when these call for the lifting of heavy objects. The Albee operation with the insertion of a graft between the spines immediately above and below the injured vertebra has been proposed, but its performance will be called for only in cases of marked disability.

PROGNOSIS

It is a comparatively simple matter to say off-hand that the prognosis in injuries of the spinal cord, with or without fracture, is always grave; but, when we attempt a more critical analysis of the results we are confronted with much difficulty. Statistics as to the immediate mortality are, of course, reliable, so that we can speak with some certainty as to the death rate of injuries to the cord within a few days or a week after the accident. So, too, we may accept as final the figures of cases reported as having recovered. When we come, however, to estimate the expectation of life in cases that either have not died as the immediate consequences of the accident or have not fully recovered, we at once encounter difficulties. The quotations as to this large group must be discounted because many a case reported as improved at the time of the published record subsequently died as a direct or indirect consequence of the injury. With these qualifications I present in tabular form the records of 314 cases of fracture and fracture-dislocation of the spine which I have gathered from the literature of the years 1911 to 1915, and which are displayed in Tables IX, X, XI, and XII.

TABLE IX

PROGNOSIS OF 228 CASES OF FRACTURES ACCORDING TO INJURY OF CORD OR ROOT

	Cervical					Thoracic					Thoracic-lumbar					Lumbar				
	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated
Recovery	0	1	1	8	0	0	8	0	4	1	0	2	0	0	0	0	4	4	15	0
Improved	2	7	3	11	0	5	3	2	8	2	0	2	0	2	0	2	16	0	20	0
Unimproved	2	1	0	0	0	9	0	1	0	0	0	0	0	0	0	0	1	0	0	0
Immediate death	11	1	0	0	0	4	0	0	1	2	1	0	0	0	0	1	1	0	0	0
Subsequent death	13	5	0	1	1	4	3	0	0	0	3	1	0	0	0	3	3	0	1	0
Not stated	0	2	0	0	0	1	0	0	3	0	0	1	0	0	0	0	0	2	11	1
TOTAL	28	17	4	20	1	23	14	3	16	5	4	6	0	2	0	6	25	6	47	1

TABLE X

SUMMARY OF TABLE IX

	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated	Total	Percentage
Recovery	0	15	5	27	1	48	21.0
Improved	9	28	5	41	2	85	37.3
Unimproved	11	2	1	0	0	14	6.1
Immediate death	17	2	0	1	2	22	9.6
Subsequent death	23	12	0	2	1	38	16.7
Not stated	1	3	2	14	1	21	9.3
Total	61	62	13	85	7	228	100.0

That the prognosis is more grave in complete than in partial lesions, of course, goes without saying. That the higher the lesion, the more grave the prognosis is equally true. Thus in 28 cases of complete transverse lesions in the cervical region there were 24 deaths; of 23 cases of lesion in the thoracic region, but 8 deaths immediately or subsequently.

A glance at the percentage column of Table X is interesting in that it records one-fifth of the cases or 21 per cent as having recovered. This is a larger percentage of recoveries than is usually acknowledged. Almost 10 per cent died as the immediate result of the injury and 17 per cent

TABLE XI

PROGNOSIS OF 86 CASES OF FRACTURE-DISLOCATION ACCORDING TO INJURY OF CORD OR ROOTS

	Cervical					Thoracic					Lumbar				
	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated
Recovery	0	2	1	6	0	0	0	0	0	1	0	1	0	0	0
Improved	1	7	3	2	0	4	6	0	2	0	4	5	0	2	0
Unimproved	0	2	0	6	0	2	0	0	1	0	0	0	1	0	0
Immediate death	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subsequent death	9	0	0	0	0	7	0	0	1	1	0	3	0	0	0
Not stated	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Total	14	11	4	14	0	14	6	0	4	3	4	9	1	2	0

subsequently, so that all that can be stated positively with regard to fractures of the spine with or without injuries of the cord is that the immediate mortality is 10 per cent and the percentage of recoveries 21 per cent. How many of these cases grouped under improved or unimproved subsequently died, of course, must remain undetermined.

TABLE XII

SUMMARY OF TABLE XI

	Complete transverse lesion	Partial lesion	Root involvement	No involvement of root or cord	Not stated	Total	Percentage
Recovery	0	3	1	6	1	11	12.8
Improved	9	18	3	6	0	36	41.9
Unimproved	2	2	1	7	0	12	14.0
Immediate death	4	0	0	0	0	4	4.6
Subsequent death	16	3	0	1	1	21	24.4
Not stated	1	0	0	0	1	2	2.3
Total	32	26	5	20	3	86	100.0

The commentary upon Tables IX and X applies as well to Tables XI and XII. There is a higher death rate in fracture-dislocations of the cervical region than of the thoracic and higher in the thoracic than in the lumbar. In the composite Table XII we find the percentage of recoveries only 12 per cent in fracture-dislocations, as compared with 20 per cent in fractures alone; but, what is perhaps unexpected, the immediate mortality after fracture-dislocations is only 5 per cent, as compared with 10 per cent after fractures. There is, however, very little to be gained by too critical an analysis of these statistical tables.

With a view to determining the expectation of life and the question of incapacity, I attempted to trace 75 cases which had been operated upon and later discharged from the hospitals of Philadelphia. Of this number but 28 could be traced, and the results are here recorded:

TABLE XIII

Years between time of accident and report	1–1½	1½–2	2–3	3–4	4–5	5–10	Over 10	Total
Entirely well	..	2	1	..	..	3	1	7
Partially incapacitated	1	2	1	1	2	..	..	7
Confined to house	1	2	2	2	..	..	..	7
Confined to bed	1	..	..	1	2	..	..	4
Died	1	1	..	..	1	..	..	3

From this it will be seen that one in four was entirely well, one in four partially incapacitated, one in two and one-half completely incapacitated, and one in nine died subsequent to discharge from the hospital, one, two and four years respectively. In none of the twenty-five survivors was there any residual involvement of an upper extremity—from which one could imply that none of the lesions were high; in ten there was partial or complete loss of bladder and rectal control.

Of practical moment is the effect of the injury upon the earning capacity. An inquiry into the 25 cases that were traced brought the following replies:

Earning capacity unaffected	7
" " reduced	7
" " lost	11
Total	25

In considering the same question, Gaugele analyzed the results of 27 cases of fracture of the vertebrae. Of these 27 cases 3 completely recovered, 1 in two years, and 2 within five years. Ten years after the injury earning capacity in 12 cases was estimated as follows:

1	reduced	10 to 30 per cent
3	"	30 to 50 per cent
4	"	50 to 100 per cent
4	"	100 per cent

To recapitulate: ten years after the accident, 1 in 9 entirely recovered; about 1 in 3 was partially self-supporting; and 1 in 7 was entirely incapacitated.

TRAUMATIC SPONDYLITIS

In considering the late effects of trauma, attention is naturally directed to what has come to be called *traumatic spondylitis* or *Kümmell's disease.* While there is considerable doubt whether this is a clinical entity, nevertheless, by way of introduction, I will briefly present the features of the disease to which Kümmell's name is attached. Trauma, be it mild or severe, direct or indirect, is regarded as a predisposing cause. It seems to matter little whether the trauma be mild or severe; at least, in many cases, the former prevails and the patient, while perhaps being completely incapacitated for a few days and experiencing some pain in the back, will resume his occupation. Several months later, however—it may be four or six months, or perhaps a year—there will be a reappearance of pain—perhaps in the form of intercostal neuralgia—together with some weakness of the lower extremities which may determine an uncertain gait.

An interesting diagnostic feature of Kümmell's disease is the formation of a kyphosis or gibbosity somewhat analogous to that of Pott's disease, chiefly in that the projection is not so prominent and does not involve so many vertebrae. It is assumed in Kümmell's disease that the deformity is not due primarily to a fracture, dislocation, or in fact to any serious injury of the spine, but that as a result of the initial injury there develops a rarefying osteitis in the bodies of one or two vertebrae. This so alters the structure of bone that the bodies become compressible, and as a result there develops the characteristic kyphosis. The radiating pains of which the patient complains are probably due to the compression of the roots as they pass through the intervertebral foramina. The only case in my experience which in any way corresponds to the conventional description of Kümmell's disease is the following:

The patient, a man, *aet.* 42 (File No. 31087), was admitted to the University Hospital in February, 1916, with the history that on May 23, 1914, he tripped and fell, and in falling thought he struck a tree. Immediately after the injury there was an area of contusion on the back which later disappeared. He was able to walk and continued his occupation, but complained of pain in the back which radiated to either side of the abdomen. There were no pains referred to the legs, no twitchings and no trouble with either bladder or rectum. Eight months after the accident the pain in the back had become so severe that he was unable to lie down at night, and could only sleep and rest in the chair. At that time turning or twisting elicited great pain, not only in the back, but down both legs. He was totally incapacitated and stayed quietly at home for two months, spending most of his time in a chair. After this, however, he gradually improved, at least, sufficiently to be able to move about with some comfort, but not, however, enough to enable him to go back to work. For the past twelve months he has improved to a considerable degree, though slowly. He has now no pain while lying down or while walking on an even surface. Any jarring, however, twisting, turning or leaning over does elicit pain, and he still has pain radiating around the abdomen above the level of the umbilicus.

The physical examination elicited the following: There is a kyphosis (Fig. 206) at the level of the twelfth thoracic vertebra and below this a slight deviation of the spine to the left. The lower thoracic and lumbar spine is rigid and immobile, and in attempting to pick anything off the floor the patient can only do so by bending the knee and hip joints. There is marked tenderness over the spinous process of the twelfth thoracic vertebra. There are, however, no sensory or motor disturbances of the back, abdomen, perineum or lower extremities. The right knee jerk and the Achilles jerk are slightly increased. There is no ankle clonus and no Babinski reflex. The roentgenogram shows evidence of compression of the last thoracic and first lumbar vertebrae. The bodies of the vertebrae have apparently disappeared and they seem to be fused with those immediately above and below the injury.

Dr. H. K. Pancoast, who took the x-ray, was unwilling to exclude the possibility of the lesion being one of tuberculous spondylitis.

While realizing the skepticism with which many look upon Kümmell's disease as an entity, I would be quite unwilling in this case to regard it as a tuberculous spondylitis. There were many points in the history

of the case certainly not characteristic of Pott's disease, and the subsequent history rather bears out this point of view. Of course, there are many cases on record in which the spinal deformity may not be so con-

FIG. 206.—THE KYPHOSIS OF TRAUMATIC SPONDYLITIS (KÜMMELL'S DISEASE).

spicuous a feature, so that there are other conditions from which the clinical picture of Kümmell's disease must be differentiated.

One's mind naturally turns to the ankylosing forms of spondylitis, to hypertrophic arthritis and to the hysterotraumatic injuries of the spine.

No doubt in the past many cases recorded as hysteria, neurasthenia, or even "railway spine," would in the light of modern x-ray studies be grouped under another category when a definite lesion of the vertebra, whatever its origin, accounts for the symptoms. Of all the diseases, however, naturally Pott's disease would most nearly simulate Kümmell's disease in that stage at which the kyphosis has developed. Both conditions may be the result of moderate trauma; in both there is fixation of the spine, tenderness and radiating pains. The prognosis, naturally, is more favorable in Kümmell's disease than in Pott's disease; while one cannot restore the structures to their normal state, the process of destruction may be arrested by physiological rest and further deformity by fibrous or bony ankylosis between the affected vertebrae precluded. With the aid of a brace or corset the patient may be able to resume his occupation, but is seldom capable of violent effort without some support.

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CHAPTER VII

STAB AND GUNSHOT WOUNDS

While stab wounds of the vertebral column are rare as compared with the other forms of spinal trauma, gunshot wounds have assumed a great importance since the outbreak of the European War and deserve special mention.

STAB WOUNDS OF THE SPINE AND SPINAL CORD

Mechanism.—Stab wounds are always inflicted by a sharp or pointed instrument, such as a sword or a knife, particularly the ever-present pocket knife. In angry broils between workmen it sometimes happens that various instruments, such as a gimlet, a shoemaker's knife, or a sickle, have been used for this purpose, and cases have been reported in which the cord has been injured by such small instruments as wire hair pins or hat pins. Indeed, it has been recorded by Rose that the cord has been punctured, leading to meningitis and death, by a needle carelessly left in a garment. But in the great majority of instances the wounding instrument is a knife with a smooth, sharp blade. The thrust is almost invariably made from behind, since the object of all intentional injuries of this nature is to take the victim by surprise. In Croly's case, however, a child pushed a small steel rod into the cord through the mouth, and Chauvel mentions a stab wound and puncture of the cord by a thrust through the abdomen.

Morbid Anatomy.—Since the assailant usually attempts to strike his opponent as near the neck as possible, stab wounds of the spine and spinal cord are most frequent in the cervical and upper thoracic regions and most rare in the lumbar. Indeed, the latter is entirely outside the swing of the arm in most instances, but even though the cervical and thoracic regions were missed and the swing of the arm sufficiently low to reach the lumbar spine, it would require a very powerful blow to effect more than a superficial lesion at this level, because of the greater strength of the lumbar vertebrae and the greater obliquity of the angle between the knife and the vertebral column. Occasional cases have been reported, however, in which the knife has penetrated the lower thoracic vertebrae and caused severe injury to the upper lumbar segments of the cord, as in one of van Gehuchten's cases, in which there were two wounds on the left side of the vertebral column: one 8-10 cm. from the spinous process

of the seventh thoracic vertebra; the other 3 cm. to the left of the twelfth thoracic vertebra. The symptoms pointed to a lesion of the cord at the level of the second and third lumbar segments. In 81 cases collected by Wagner and Stolper, the cervical region was involved in 39 instances, and the upper thoracic in 42. In the series of 93 cases of stab wounds of the spinal cord upon which Petrén based his studies on the conduction of impulses for deep sensation, the injury was located in the cervical region in 43 cases, and in the thoracic in 50, but in the latter the lesion was situated below the sixth thoracic vertebra only eleven times.

The extent and nature of the damage inflicted upon the vertebral column and its neural contents by sharp or pointed instruments vary according to the level of the injury, the strength of the blow and the character of the instrument. A knife may pierce or even fracture one of the vertebral processes without penetrating the canal. On the other hand, the meninges and cord may be severely contused, punctured or even completely sectioned, while the vertebral column remains entirely intact. This is illustrated by the following case operated upon by Dr. Francis T. Stewart:

Stab wound of the cord between the sixth and seventh cervical vertebrae with an incomplete lesion. Operation; suture of the cord; death of the patient nine days after operation.

The patient, a colored man, *aet.* 27, was admitted to the service of Dr. W. W. Keen in the Jefferson Hospital, December 10, 1911. The day prior to admission, while drunk, he was stabbed in the neck, the knife passing between the sixth and seventh cervical vertebrae. He was completely paralyzed in the lower extremities and partially paralyzed in the upper limbs. There was some power remaining in the biceps, triceps and deltoid of each side. Anesthesia for touch extended up to a line passing horizontally through the second costosternal articulation and there was also an area of tactile anesthesia on the ulnar side of the left upper limb, including the little finger. Loss of pain sense corresponded to that of tactile anesthesia. The knee jerks and Achilles tendon jerks were absent. The cremasteric reflex was present on the left side but absent on the right. The breathing was abdominal in type. The sense of position was probably preserved in the extremities.

Operation.—The patient was operated upon by Dr. Francis T. Stewart on December 10th. The spinous processes of the sixth and seventh cervical vertebrae were removed and it was then seen that the cord had been more punctured than cut by the knife and it appeared that the middle two-fourths of the cord had been destroyed. One catgut stitch was taken in the cord substance, the direction of the stitch being parallel to the cord. An examination made four days after the operation records that the sense of touch and pain was preserved in the left leg. From the record before the operation this indicates a return in function. In the same record is noted that on the right side of the trunk the patient feels pin prick, the same obtaining in the right lower limb. Nevertheless, the patient began to fail and died on the 19th of December. It is worthy of note that the bladder contents just before death were "almost wholly blood."

This is particularly prone to occur in the cervical region, where the vertebrae are relatively small, the arches far apart, and the spinous proc-

esses slanting obliquely downward. Indeed, the cord may be irreparably damaged, even though the dura may not have been penetrated.

The bone lesion in these cases is, therefore, by no means constant. Although it is more usual for the instrument to pass between the arches of the vertebrae in the cervical region, it occasionally happens that an arch or spinous process is perforated and sometimes actually fractured, as in Alessandrini's case, in which there was a fracture of the arch and transverse process of the sixth cervical vertebra. In the thoracic region where the vertebrae are relatively more resistant and in closer proximity, a blow which inflicts injury on the cord must perforate the vertebra, unless the invading instrument should have a very fine point. Thus, fractures are more frequent at this level. It often happens, however, that the knife proves less resistant than the bone, and a piece of the blade becomes broken and remains lodged, sometimes in the vertebra itself, sometimes partially within the canal.

Whatever the nature of the bone lesion, it is always comparatively slight, and the gravity of the prognosis depends entirely upon the extent and degree of the injury to the contents of the canal. Extradural bleeding is usually insignificant, since the plexuses of veins on the anterior surface of the cord are seldom involved. Laennec has reported a case in which there was a concomitant injury to the vertebral artery. Occasionally, as in the case recorded by Rauzier and Rimbaud, there is a cerebrospinal fistula with free escape of cerebrospinal fluid, which greatly complicates the situation by enhancing the danger of infection. Their patient had received a blow with a stiletto at the level of the fourth thoracic vertebra, and immediately fell to the ground with complete motor and sensory paralysis up to the level of the last rib. From the wound, which was small and oval in shape, measuring about 1 cm. at its greatest diameter, there appeared a jet of cerebrospinal fluid, and the fluid continued to escape for about thirty hours, saturating the bandages and the bed. The paraplegia remained unchanged during the first nine days, at the end of which time the patient began to have painful sensations in the right lower extremity, and gradually sensibility returned for all forms of cutaneous sensations in this extremity, but anesthesia remained complete in the left. The motor disturbances manifested a similar improvement, with gradual return of voluntary movements in the left lower extremity, while the right remained paralyzed.

The escape of cerebrospinal fluid, however, is no criterion as to the penetration of the dura or the presence of a cord lesion. Since the wound is seldom wide and gaping, the overlying soft parts frequently prevent the escape of fluid, even when the instrument has pierced the dura. On the other hand, the cord may be severely contused and the dura remain intact, or the meninges may have been penetrated with escape of cerebrospinal fluid and no injury to the cord. In most instances,

however, the instrument is sharp, the dura is cut, and the aspect of the cord coming in direct contact with the blade appears smoothly sectioned. Occasionally, the cord has been completely sectioned. In the 16 fatal cases in Wagner and Stolper's collection there was complete division of the cord in 4 (Petit, Staub, Vogt, Hofmeister). More often only a portion of the cord is directly involved—edema, hemorrhage, or slight transitory contusion, giving rise to the picture of a complete transverse lesion which is so often present immediately after the injury. The changes in the cord substance, macroscopical and microscopical, primary and secondary, differ little from those resulting from other varieties of spinal trauma (*vide* pp. 393, 396) with the exception that in stab wounds the nature of the injury renders the possibility of infection more remote and the hope of at least partial recovery much brighter.

Symptomatology.—If the damage be limited to the outer aspect of the vertebral column and the overlying soft parts, there will be a small wound of the integument, varying in width according to the size of the weapon, and more or less edema and ecchymosis of the adjacent soft parts. Occasionally one may find local tenderness, crepitus or preternatural mobility, indicating an isolated fracture of an arch or spinous process, but usually one must resort to the roentgenogram to demonstrate the presence of such lesions, as probing should never be employed.

In most cases the blow is sufficiently strong to penetrate the canal and cause grave damage to its contents. Whenever the cord is involved, either directly or indirectly, grave symptoms appear almost immediately after the blow. The patient becomes paralyzed and falls to the ground. It is difficult to determine at first whether the cord has actually been penetrated or merely contused, the escape of cerebrospinal fluid being, as we have seen, no certain criterion. The sensory, motor, reflex and trophic disturbances arising from either direct or indirect involvement of the cord, vary naturally in their expression according to the level of the cord lesion and the particular columns involved. Immediately following the injury there is almost invariably the picture of a complete transverse lesion, but this gradually subsides until the patient presents only a Brown-Séquard syndrome, which, however, is seldom typical, because there are few pure hemisections of the cord. This retrogression of symptoms is due to the fact that, with the exception of those few rare cases in which the cord has been completely divided, only a portion of the cross section is directly involved, the remainder of the medullary substance being merely compressed or contused and susceptible, therefore, to more or less complete regeneration when the source of compression or irritation is removed. Hence the importance of detecting the presence of a fracture or foreign body. A small broken fragment of an instrument may lie quiescent for years, as in Perthes' case, in which no untoward symptoms appeared until

twenty-seven years after the injury, and then suddenly caused grave disturbances.

While in some cases the instrument follows a fairly straight course until it reaches the canal, it may deviate so far as to involve the side of the cord opposite its point of entrance, as in a case reported by Pallasse and Espengel, in which a blow was inflicted on the left side of the neck about six centimeters to the left of the spinous process of the sixth cervical vertebra; but the symptoms were all indicative of a lesion of the right side of the cord. The wound, which was only about one centimeter in length, healed quickly, and there was gradual improvement in all the symptoms. Six months after the injury, however, there was still an incomplete hemiplegia with contractures on the right side, and on the left, anesthesia for pain and heat. The author concludes that the blade must have passed through the intervertebral foramen and in front of the cord, the head being turned to the left at the time of the injury. Georges reports a somewhat similar sequence of events in the case of a woman who had received several wounds with a knife in the back. At autopsy it was found that the knife, which had penetrated the skin and soft parts on the left lateral posterior aspect of the neck, had passed between the laminae of the fourth and fifth cervical vertebrae and finally involved the meninges and cord posteriorly.

Treatment.—The surgical treatment of stab wounds of the spine and spinal cord must take into consideration the wound, the presence of a foreign body, a cerebrospinal fistula and the injury to the cord. The majority of wounds are not infected and it is the surgeon's duty to maintain asepsis by cleansing and disinfecting the skin about the wound of entrance, and by the application of a sterile protective pad. In some instances, by the character of the instrument, by the ragged appearance of the external wound, and by the evident soiling of the wound, the likelihood of infection may be anticipated. Under such circumstances the tract should be disinfected with iodin, a small tampon introduced for drainage and the wound dressed daily. The presence of infection in the wound is not a matter of very great consequence if there be no direct communication with the subarachnoid space, but in the presence of a cerebrospinal fistula every means must be provided for adequate drainage. As probing is always inadmissible, a roentgenogram should be taken as soon as possible to determine, first of all, whether any part of the instrument broke off and lodged in the wound, and especially whether this fragment might lie within the dural sac or be in contact with the cord.

After the care of the wound, the question at once arises: Is an exploratory operation called for? Let us consider this first from the viewpoint of the foreign body. If the x-ray reveal a piece of the weapon broken off and lodged in the wound, I would consider it incumbent upon the surgeon to operate when the fragment is in contact

with membranes or cord. In Schnitzler's case the patient recovered from the immediate effects of the stab wound with a Brown-Séquard syndrome. Three months after the operation, the x-ray discovered the point of the knife, 5 cm. long, at about the level of the fourth or fifth thoracic vertebra. Upon removal of the spinous processes and the right half of the laminae of the third and fourth thoracic vertebrae, the fragment was found embedded in the arch of the fifth thoracic vertebra, and upon its removal there was a rapid improvement. Somewhat similar was the experience in a patient of Bettner's who had been stabbed in the lumbar region. He complained of pain in one thigh and knee, of some paresthesia, and a train of nervous symptoms—among others, attacks of vertigo and a sense of fear. Failing to find the evidence of a retained foreign body with the roentgenogram, it was thought the patient was a neurasthenic, but as the symptoms persisted a second roentgenogram was made, and the point of a knife blade was found embedded in the transverse process of the third lumbar vertebra, in such a way as to irritate the posterior ganglia. Its removal was followed by complete recovery.

As a rule the signs of pressure appear immediately after the injury and continue until the foreign body is removed, but occasionally the presence of the foreign body may not make itself manifest for some time, and in this connection I might refer to the case under the observation of Perthes, where the symptoms of pressure did not develop until twenty-seven years after the injury. The appearance of phenomena after a considerable interval may be due to the pressure upon the cord of the products of infection or oxidation of the foreign body. Another example, where the late consequences of a retained foreign body are well illustrated, is Durand's case of stab wound between the eighth and ninth thoracic vertebrae. The wound was inflicted fourteen years before, and was followed immediately by the formation of abscesses, which continued to discharge, off and on, for three years. The infection subsided and the wound healed, but after an interval of eleven years, signs of infection recurred, and upon opening an abscess, Durand found the point of the knife blade between the spinous processes of the eighth and ninth thoracic vertebrae. From these examples of early and late disturbances arising from the presence of a foreign body, the indications for its removal are clear enough.

The escape of cerebrospinal fluid is always a cause for alarm, and at once suggests the question of operative intervention. To be sure, there have been many cerebrospinal fistulae, which have closed spontaneously and uneventfully, but others, again, have been the means of transmitting an ultimately fatal infection to the meninges. Though there may be conditions under which conservative practice would seem to offer the greater chances of recovery, yet, I believe, in the long run immediate exposure and closure of the wound in the meninges will prove to be the safer

course. Contamination of the meninges occurs chiefly through extension from an infection which develops along the stab wound, and the sooner the fistula is closed, the greater the protection to the meninges. There have been a number of instances in which the operation has been deferred until meningitis developed, and while in some the patients recovered, in as many the patients died.

Finally, as an indication for operation, comes up the momentous question of the cord injury. Is anything to be gained by an immediate or a late exploratory operation in any one of the three damaging lesions, contusion, hemorrhage or section? If, for other complications already discussed, there be no positive indication for an exploratory laminectomy, I question the propriety of an operation performed in the hope of deriving benefit in a cord contused, the seat of hemorrhage, or severed, in whole or in part. The principles underlying the question of operation in injuries to the cord from stab wounds are fundamentally the same as those for injuries to the cord from fracture and dislocation, and these have been very thoroughly discussed in the earlier part of this chapter. Suffice it at this time to say, that I do not entertain in any particular the possibility of cord regeneration, and, therefore, cannot recommend operation as a means of offering relief, where such is to be anticipated from cord suture.

Prognosis.—The causes of death after irreparable damage to the cord are alike, no matter what the character of the injury. Since many stab wounds are in the cervical region, respiratory failure is an occasional cause; but the most common cause is meningitis. Of 15 deaths in 40 instances of stab wounds of one kind or another, where the meninges were involved, Thorburn found 9 due to infection.

Of the late consequences decubitus and infection of the urinary tract are most to be feared. In a series of 46 cases collected by Roeseler, the mortality in the cervical region was 40 per cent and in the thoracic 31 per cent; the higher the lesion, the higher the mortality. Thus, at the level of the two upper cervical vertebrae it was 71 per cent, at the level of the fourth 53 per cent and at the level of the fifth, sixth and seventh 23 per cent.

An impression of the vulnerability in stab wounds, and of the possibility of recovery irrespective of the extent of injury, may be had by assembling the statistics of a group of 81 cases collected by Wagner and Stolper, and 67 cases by Enderlen:

Complete recovery	14 per cent
Permanent improvement	65 " "
Deaths	21 " "

With regard to recovery of function, the prognosis is always grave. In by far the majority of cases, the functional disturbance, whether motor

or sensory, continues unrelieved, more or less, according to the extent and character of the cord injury, despite attempts at cord suture. In reviewing the results of 21 who survived stab wounds which involved the cord, Thornburn found only 3 complete recoveries; in 16 paralysis or anesthesia or both had persisted, and 2 were said to be improving. A definite forecast as to the outcome of the case should not be attempted too soon after the injury, for in some instances a patient, with what appears at first sight to be a complete section of the cord, may later on recover more or less function. It may be a matter of weeks or months before the maximum improvement is attained, and, as a rule, when there is restoration of function, its resumption appears first in the return of power to bladder and rectum, then of sensation and finally of power in the extremities. As a rule, relatively more strength is restored to the upper than the lower extremities, but with return of power there is often more or less spasticity.

GUNSHOT WOUNDS OF THE SPINE AND SPINAL CORD

Wounds of the spine and spinal cord are among the most serious of war injuries, and owing to the greater velocity and power of penetration of the modern bullet, they are becoming both more frequent and more grave. In the American Civil War they formed about one-fourth of 1 per cent of the total number of wounds, in the Spanish American War about 0.55 per cent, in the Balkan War about 0.6 per cent, and according to the reports thus far received they constitute a still larger proportion of the wounds of the present war. In these injuries the cord is almost invariably involved either directly or indirectly. They, therefore, form one of the saddest groups with which the surgeon has to cope. Although the reports from the European front are somewhat fragmentary and superficial because of the stress of the work, nevertheless, they are sufficient to give us an insight into the various types of lesions of the spine and cord and the general attitude of the surgeons at the front toward the problems of treatment and prognosis.

Pathological Anatomy.—Wounds of the spine and spinal cord occur at every level, although they are most frequent in the thoracic region, chiefly because it is longer and, therefore, more exposed. Out of 642 cases of gunshot injuries of the vertebrae recorded in the "Medical and Surgical History of the War of the Rebellion," 91 were in the cervical region, 137 in the thoracic, 149 in the lumbar, 2 in the cervical and thoracic, 3 in the thoracic and lumbar, and in 260 cases the location was not stated. In 1906, Prewitt collected 49 cases of gunshot wounds of the spine which had been treated since the introduction of antiseptic surgery, and in this series the cervical region was involved in 18 cases, the thoracic in 26, and the lumbar in 5. In 46 cases treated during the next

ten years and tabulated by Haynes and Moorhead, 11 involved the cervical region, 31 the thoracic, 3 the lumbar and 1 the sacral. The injury was located in the thoracic region in 12 out of 16 cases of spinal wounds in the Balkan War (Exner), and when the time comes for more detailed reports and tabulations of the spinal injuries in the European war, the proportion will probably be very similar to that indicated by the above figures. In a group of over 300 cases seen by Gordon Holmes in the present war, the injury most often affected the thoracic region and the cervical enlargement, although he has seen every segment involved from the second cervical to the conus. In 65 cases the lesion was situated between the sixth and ninth thoracic segments, and in the fourth, fifth or sixth cervical segment in 51 cases.

In most respects, however, the present conflict in Europe is necessitating a slight revision of our ideas concerning the pathological anatomy of spinal injuries. Not only are wounds of the spine and spinal cord much more frequent than they have been in previous wars because of the greater velocity and power of penetration of the modern bullet, but the mortality is much higher, and in the cases which are not immediately fatal the damage both to the extramedullary structures and to the cord itself is much greater.

Bone Lesions.—The bone lesions resulting from gunshot wounds of the spine are varied, depending partly upon the portion of the vertebrae involved, and partly upon the shape and velocity of the projectile and upon whether it has ricocheted or followed a straight course. Fractures of the compact and thin parts, particularly the arches, spinous and transverse processes, are common. The same projectile, particularly if it be a ricocheting bullet, may involve several arches and their processes, and if its power of penetration be sufficiently strong at the point of impact, it may cause indirect fracturing of the arches and processes immediately above or below those directly involved. Associated with these fractures there is considerable splintering and fissuring of bone. Indeed, the force of impact and velocity of the modern bullet are so great that dislodged spicules of bone and metallic particles of the projectile itself, or even bits of clothing, may be carried forward into the spinal canal, greatly adding to the damages inflicted upon the cord and its coverings and to the danger of infection.

The bullet may strike the spinal column anteroposteriorly instead of in the more usual postero-anterior direction. In this case there is usually, in addition to the spinal injury, a wound of the pelvic, abdominal or thoracic viscera, thereby enhancing the chances of infection. The bone lesion is not so severe, however, as gunshot injuries seldom cause a comminuted fracture of the vertebral bodies. The bodies of the vertebrae are less compact and therefore are perforated, notched or fractured by the projectile in a more or less clean-cut fashion. If the course of the

projectile be transverse or oblique, the transverse and articular processes are chiefly involved.

Cord Lesions.—While the bullet may become lodged in the vertebral bodies, in the laminae or other processes or in the vertebral canal, it more often happens, owing to the greater momentum of the modern projectile, that the bullet either passes through the entire spinal column or, in case the bone at the point of contact be more resistant, it may rebound without penetrating the bone and become embedded in the soft parts at some distance from the spine. Occasionally, the bullet, instead of remaining in its original location, sinks to a lower level of the canal.

It is, therefore, evident that the cord may suffer in a variety of ways both directly and indirectly. It may be severely lacerated or even completely severed by direct contact with the bullet or indriven pieces of bone; it may be compressed by displaced fragments of bone, by the bullet protruding into the canal, by a subdural hemorrhage, adhesions or serous exudates; it may be contused by the bullet and accompanying splinters of bone; and finally the cord may undergo grave structural changes from the effects of concussion or commotion caused by a bullet striking some portion of the vertebral column and bounding back to become lodged in the soft parts, or the sudden atmospheric changes produced by the explosion of shells in the neighborhood may result in changes in the spinal cord. The more detailed reports from the front would lead us to believe that the indirect type of injury is the more usual, but it is quite impossible to draw a sharp dividing line between the extensive lacerations of direct injury and those changes due to compression, contusion and concussion, the indirect types, since all of these conditions may be combined in the same case. The same fragment of bone may both compress and lacerate the cord; moreover, a bullet which penetrates the canal and the cord itself may strike the vertebral column with such force that the cord may suffer from the effects of concussion at points quite remote from the point of impact.

As an example of an indirect injury the following case of Jumentié is cited:

Bullet wound of the spinal column fracturing the arch of the third thoracic vertebra, without any external evidence of cord injury. The autopsy revealed an hematomyelia involving six thoracic segments.

The bullet had entered the right shoulder blade at the level of the spinal border and found its exit at the anterior fold of the left axilla. It had traversed the thorax, as evidenced by the dyspnea, slight hemorrhagic expectoration, fine râles and signs of a pleural effusion.

From the complete and total paralysis, it seemed that the cord must have been injured. There was absolute loss of motion and sensation in the lower limbs and trunk, and complete retention of urine. The reflexes were totally abolished, except for a slight flexion response in the small toes of the left foot. Large areas of dis-

coloration and beginning decubitus were noted on the sole and the external border of the foot.

The patient was under observation five days. During this time the only change noted was in the reflexes. That of the toes had disappeared on the third day; but the patellar reflex re-appeared first on the left and then on the right. It consisted merely of slight contraction of the quadriceps without provoking any movement.

The patient died on the fifth day. An autopsy was performed and the following conditions noted: The bullet had passed through the right shoulder blade and muscles of the vertebral column at the level of the third thoracic vertebra, and after fracturing its spinous process at the base, *without entering the spinal canal,* it had shattered the left half of the posterior arch of that vertebra and its transverse process; then, after fracturing the head of the third rib, it had penetrated the

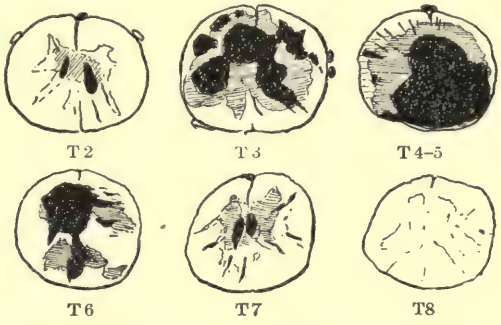


FIG. 207.—HEMATOMYELIA CAUSED BY BULLET STRIKING THE SPINAL COLUMN AND FRACTURING THE ARCH OF THE THIRD THORACIC VERTEBRA, WITHOUT ANY EXTERNAL EVIDENCE OF CORD INJURY. (After Jumentié.)

The autopsy revealed an hematomyelia involving six thoracic segments.

thoracic cavity. Here it produced a slight hemothorax, entered the apex of the lung and caused a large infarct, and finally, after fracturing the first rib, made its exit close to the anterior fold of the axilla.

In spite of the injury to the third thoracic vertebra there were no indications of hemorrhage in the spinal canal or cord—only a very slight sanguineous coating of the posterolateral portion of the dural sac around the lower cervical and the upper thoracic ganglia. The dural sac was intact and the spinal fluid perfectly clear.

The cord itself appeared almost normal; there was a slight increase in size, suggesting edema, at the level of the first five thoracic segments and a slight discoloration. The arachnoid of the posterior surface in this region was bluish white in appearance and the posterior spinal veins were distorted and distended up to the cervical region. There was *no external evidence whatever of contusion or other injury to the cord itself.*

These findings did not harmonize with the clinical manifestations; but after the cord was sectioned a large hematomyelia was found in the upper thoracic region, from the second to the seventh segment (Fig. 207).

The hemorrhagic focus at the second thoracic segment appeared in the form of two small specks in the central gray matter near the base of the posterior horn. In the next segment, T_3, the clot filled and surrounded the gray matter with disseminated islets in the anterolateral tract. Between T_4 and T_5, the clot was largest and was represented in size by the diameter of the cord. In the next two segments, T_6 and T_7, the clot gradually diminished in size.

The development of this enormous hematomyelia in the absence of any signs of hemorrhage within the spinal canal, and the integrity of the dural sac were noteworthy features. The bullet evidently had not injured the cord directly and the hematomyelia must have been due to the concussion occasioned by the fracture of the lamina. The broken fragment had not encroached upon the vertebral canal and therefore could not have come in contact with the cord.

Laceration.—Direct injury of the cord by the bullet or accompanying secondary missiles results in grave forms of laceration and even complete severance. If the projectile be a ricocheting bullet of high velocity and accompanied by secondary missiles, the havoc is extremely grave, the cord being reduced to the substance of pulp, as in one of Derby's cases in which the patient presented a complete flaccid paralysis of both lower extremities with absence of reflexes and loss of muscular sense, when he was brought to the American Ambulance in Paris twenty days after injury. The bladder and rectum were paralyzed; there was considerable atrophy of the muscles of the thighs and buttocks, and decubitus was present. The roentgenogram showed a shrapnel ball directly opposite the intervertebral disk between the eleventh and twelfth thoracic vertebrae. At the operation the dura under the ball was found badly lacerated and the cord reduced to the consistency of pulp. There was naturally no improvement after the operation. In another case reported by Derby, "the dura was found to be in shreds, and the cord divided, except for a few nerve filaments. Several small bone fragments were removed from the spinal canal."

Not infrequently the cord is smoothly sectioned by the passage of the bullet, as in the Stewart-Harte case, the Fowler case, and the more recent case of Giron, in all of which cases suture of the cord was attempted. Rumpf reports a complete severance of the cord in a 19-year-old soldier who had received a wound on the right side of the back between the tenth and eleventh ribs. He suffered from excruciating pains in the back below this level and in the region of the bladder. There was motor and sensory paralysis of the lower extremities, the reflexes were completely lost, the bladder and rectum paralyzed and decubitus was present. Despite a negative roentgenogram, an operation was undertaken, and it was found that the bullet had penetrated the arch of the eleventh thoracic vertebra and completely sectioned the cord. Moreover, splinters of bone had become imbedded in the dura both above and below the point of section, accounting for the severe pains. Although the pains ceased after the operation, the decubitus continued and the patient died; the autopsy revealed a diffuse peritonitis.

In cases in which the cord has been completely severed, the divided ends are extremely swollen, edematous and soft, often semifluid in consistency and surrounded by clot and spicules of bone. If the wound has been infected there will be signs of meningitis spreading both upward and

downward. The microscopical changes resulting from these injuries have been carefully studied by Gordon Holmes in some fifty cases and described in detail in his Goulstonian lecture from which I quote *verbatim:*

Microscopical examination always shows that there are severe and relatively extensive changes in the spinal cord immediately above and below the lesion; for the distance of half a segment at least and often further the tissue is completely softened and none of its normal elements are recognizable. Under the microscope only ruptured disintegrating axis cylinders and globules and irregular masses of myelin can be seen; the latter rapidly become smaller and smaller and are absorbed by the numerous scavenger cells which quickly pervade the tissue. Hemorrhages generally small but occasionally of considerable size, are usually found in these softened areas, but they are more common and, as a rule, larger in the gray than in the white matter. In many cases, however, hemorrhages have been rare or very small, and they are evidently not an essential feature of the condition. The blood vessels are always engorged, but they are, as a rule, thrombosed only in the immediate neighborhood of the primary wound. The most striking feature in these sections, however, is the presence of large spherical or irregular cells, which are frequently, apart from the blood vessels, the only recognizable tissue elements. . . . These are obviously compound granule cells, . . . derived from the neuroglia. . . .

A proliferation of connective tissue elements around the smaller blood vessels also occurs. They take the form of elongated spindle-shaped cells which appear to be engaged in the formation of new capillaries.

These secondary changes, which occur in the neighborhood of a laceration or division of the cord, evidently produce further destruction of it. They are obviously degenerative rather than inflammatory, and are due to the edema and circulatory disturbances that occur in the bruised and necrotic tissue on the borders of the injury, spreading into the involving parts which were not directly damaged by the missile. Edema is the most important factor; it seems to affect the vitality of the neuroglial matrix as well as of the nerve cells and fibers, and combined with circulatory disturbances leads to their disintegration. . . .

Edema of both gray and white matter with some swelling and softening of the cord is the most constant of these changes. It gradually diminishes away from the wound, and often seems to bear no definite relation to its severity.

Hemorrhages of various sizes are often associated with it, but these are less constant; they are generally small punctiform extravasations of blood, which give a mottled appearance to the cross section of the cord, but they are frequently larger . . .; a large central hemorrhage with a tendency to spread longitudinally in the cord, such as is generally understood by the term "hematomyelia," was not present in any of the fifteen cases in which the microscopical examination has been completed. These hemorrhages are found particularly in the gray matter and about the central canal; one of the most common sites is the dorsal horn, where they can obviously interrupt the reception of afferent impulses. In the gray matter they are liable to break up and destroy the tissue, but when small they produce surprisingly little change in the white columns, the extravasated cells merely tracking along the vessels or between the fibers; occasionally, however, there is some local softening, and later neuroglial proliferation, around larger extravasations.

Contusion.—While there is not a physical solution of continuity in contusion of the cord by a bullet or indriven splinter of bone, the damage is irreparable in the majority of instances. The cord becomes edematous,

and if the contusion be severe, hemorrhagic foci and secondary processes of softening appear, accompanied at a later stage by chromatolysis and other changes in the nerve cells. Quoting from Holmes once more, because of the painstaking character of his studies as compared with the hasty and superficial character of the majority of the reports from the present war, we find:

> The most important is softening and disintegration of the tissues, always greatest in the region which was directly contused. If the injury is severe the whole cross section may be softened, but more commonly there are discontinuous foci in the ventrolateral and dorsal columns. The gray matter may be also completely destroyed in whole or parts, but it is more usually extremely edematous and only partly disintegrated, with its nerve cells necrotic or in advanced chromatolysis. Occasionally only a diffuse or focal necrosis is found in which no stainable elements persist. The affected areas are gradually invaded by granule cells, and a considerable proliferation of neuroglial cells is visible around them, but, apart from a pronounced congestion of the vessels and an occasional increase of the cells in their walls, there is no evidence of any inflammatory process. The amount of hemorrhage into the injured region also varies very much.
>
> The distant lesions differ in no respect from those which are so commonly associated with direct spinal injuries. Diffuse foci of necrosis and softening, vacuolation due to falling out of fibers and the sieve-like rarefaction produced by the disappearance of fibers and of the finer glial matrix, as well as minute scattered hemorrhages, are found in the white matter of the adjoining segments, while the gray matter is also edematous, and contains similar hemorrhages and perhaps foci of softening. The central cylindrical cavities, which have been already described, also occurred in the dorsal columns relatively as frequently as with direct injuries.

Compression.—Both the cord and roots may suffer severely through irritation and later compression by a bullet or dislocated fragment of bone, projecting into the canal or lying entirely within it, and if the pressure be not promptly removed, edema, myelitis and finally necrosis and other grave degenerative changes will take place until the lesion becomes irreparable. The degree of pressure depends, of course, upon the size of the bullet and the portion of the canal involved. In the thoracic region where the lumen of the canal is narrow, a bullet of exceedingly small caliber might exert considerable pressure upon the nervous tissues, while a bullet of the same size in the lumbosacral region might cause no demonstrable pressure symptoms. But in no case is it advisable to allow the bullet to remain *in situ,* since sooner or later it will give rise to inflammatory exudates, adhesions and thickening of the dura, which eventually involve the cord seriously through pressure. Bullets and secondary missiles passing through the vertebral canal usually cause at least transitory compression of the cord, and frequently, through injuries to the meninges and the extramedullary vessels, produce a more or less extensive hematorachis, either subdural or subarachnoid (*vide* p. 385).

In some cases the disturbance caused by the bullet gives rise to adhesions of the leptomeninges and collections of fluid not unlike the patho-

logical picture presented by circumscribed serous meningitis. On the outside, the dura pulsates markedly in the upper part, while in the lower part pulsation seems to be entirely lacking, and occasionally pachymeningitic processes are present. Marburg and Ranzi cite a case in which the abnormal accumulation of fluid was attributed, not to adhesions, but rather to a displacement caused by a fracture of the sixth cervical vertebra. These collections of fluid are responsible for the pressure symptoms in many cases and call for early intervention. In one of Marburg and Ranzi's cases in which the opening of the dura had to be postponed to a second operation because the bullet was embedded in an abscess, the patient refused a second operation and the authors attribute the absence of improvement to the fact that the intradural tension was not relieved. The formation of granulation and callous tissue in the vicinity of the wound is also a frequent source of medullary irritation and compression.

Concussion.—In addition to the grave lesions of the cord caused by direct contact with or pressure from the bullet, there is now a large group of cases in which the roentgenogram shows either no bone lesion or an entirely insignificant one, while the clinical picture is indicative of severe injury to the cord. In most of these cases the bullet has struck the vertebral column and rebounded to become imbedded in the soft tissue or an organ often at some distance from the spine, but the momentum of the newer bullets is so great at the time of impact that the vibratory force is transmitted to the cord, resulting in medullary lesions varying from slight degrees of contusion to complete disintegration.

The following case reported by Allen illustrates this most aptly:

A man, *aet.* 32, was shot in the back, the bullet lodging in the vertebral column, having passed through the spinal canal and grazed in passing the dura mater covering the spinal cord at the level of the fifth thoracic segment. The symptom picture was that of almost complete solution of continuity. As the patient's condition grew steadily worse he was operated on, two and one-half months after the reception of the injury, but died twenty days after the operation. At the autopsy the cord appeared almost normal at the level of injury, but on section and microscopical examination a condition of traumatic softening involving the entire cord was found which, from the external appearance of the unsectioned cord, would never have been suspected (Figs. 208 and 208a).

Many explanations have been offered as to the cause of these changes. The momentary displacement of the vertebrae may be a contributing factor. Some attribute them to the waves of pressure set up in the spinal canal and the disturbance of the lymphatic circulation caused by the concussion. According to Fickler, the cord is made to oscillate within the canal at the time of the impact, and since its movements are not synchronous with those of the column, it may be directly injured by contact with the walls of the canal. This displacement of the cord would easily account for histological changes in the roots.

According to Claude and Lhermitte, the shock transmitted to the cerebrospinal fluid and the temporary increase in pressure brings about an ischemia sufficient to cause insulatory necrosis of the marginal vessels. The sudden modifications of the cerebrospinal pressure, moreover, these

FIG. 208.—GUNSHOT INJURY IN WHICH THE SPINAL CORD WAS CONTUSED AT THE LEVEL Y. (Allen.)
The injury at X was a laceration made at the necropsy.

authors believe, are not limited to the periphery of the cord, but may cause a distention of the walls of the central ependymal canal. It is quite possible that a number of factors may play a part in the development of these lesions; the sudden jarring of the cord might very readily be responsible for some of the anatomical disturbances and structural changes.

The following remarkable case of bullet wound, reported by Latarjet, tends to uphold the theory of lesion of the spinal cord through shock alone.

Complete section of the spinal cord through the shock of a rifle bullet which did not touch the cord. Dura and pia intact, and no hematorachis. On opening the membranes, complete section of the cord was found.

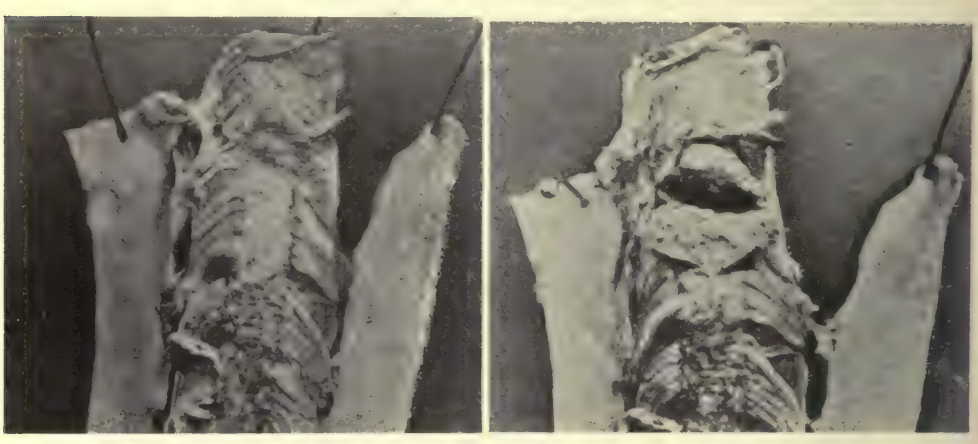
The rifle bullet entered at the left side of the head, above the angle of the jaw, at the level of the left subhyoid region, and passed out at the nape of the neck, a little to the left of the median line. The patient showed all the symptoms of complete section of the spinal cord and death occurred very shortly after the

FIG. 208*a*.—A SECTION OF THE SPINAL CORD AT THE LEVEL OF IMPACT OF THE BULLET. (Allen.)

injury. At autopsy there was found no hematoma either in the neck or at the base of the skull. There was a fracture of the left lamina of the fourth cervical vertebra, this fracture being rectilinear at the base of the lamina, which was not in the least displaced. There were no bone splinters, and the bullet, which grazed the lamina at a tangent, must have merely fractured it. When the spinal canal was opened, a very little blood was found on the external face of the dura opposite the fracture. The dural sac was absolutely intact. It was opened, but there was no blood found within, nor any lesion of the meninges. A slight diminution of the consistency of the medullary cord was noticed on contact with the finger. At this point an opening in the pia was made with a bistouri and a complete transverse section of the spinal cord was found, exceedingly clean cut, through its entire thickness (Fig. 209).

This lesion, Latarjet believes, was unquestionably caused by shock of the projectile and occurred without displacement of the lamina and with no lesion of the meninges.

Mussen believes "that shock effects can be transmitted to the spinal fluid, where they set up a hydraulic force which acts radially. And this force, by vibrating the cord, would cause it to pull on its attachments to the ligaments, which would result in the tearing of the tissue in the lateral regions and along the septa." In a series of cases of traumatic degeneration of the spinal cord in which Mussen made very careful histological examinations, there was usually localized destruction of cord substance many segments from the point of impact, the lateral regions of the cord were most frequently involved, although changes were found in various parts of the cord substance, particularly along the septa; in no case was there disturbance of the anterior or posterior roots. The degenerative changes were also found to be much more rapid than those



A B

FIG. 209.—COMPLETE SECTION OF THE SPINAL CORD BY CONCUSSION OR THE INDIRECT ACTION OF A BULLET. (After Latarjet.)

A, Showing dura intact, pia intact, no hematorachis. Note on the upper portion of the cord a slight cupuliform depression corresponding to the lesion. B, An opening was made in the pia with a bistouri and the drawing down of the flap disclosed a complete lesion of the spinal cord.

in the ordinary type of secondary degeneration, since in sixty hours Marchi degeneration and the presence of fat in the tissues were demonstrated, changes which are not found until the fourth or fifth day in cases of secondary degeneration. He concludes, therefore, that the lesions in these cases of concussion are quite distinct from the usual type of secondary degeneration and should be termed "traumatic degeneration." He believes that the chief cause of these changes is the transmission of the shock to the substance of the cord by means of the membranes and spinal septa, particularly the median and the lateral septa, which attach the pia to the cord and are so "closely connected with the supporting glia structure of the white and gray matter." Until recently the tendency has been to designate such cases as concussion of the spine, causing "molecular

disturbance" within the cord, but this seems to me, as I have already indicated, a misnomer.

The findings at operation and the results of careful histopathological studies of cords removed at autopsy all demonstrate that we are here dealing with very real lesions, such as hematomyelia, edema, myelomalacia or softening, disseminated myelitis, acute traumatic necrosis, hematorachis and arachnitis serofibrosa spinalis. In one of Cassirer's cases, there was marked myelomalacia, although the vertebral column was entirely intact (quoted by Oppenheim) and Oppenheim has made a similar diagnosis in several cases. In a case reported by Gamper, the clinical picture seemed to indicate hematomyelia involving practically all the gray substance of the posterior horns on the left side of the cord from the upper cervical region to the lumbar enlargement. The patient had received a bullet wound in the left side of the neck which was immediately followed by paresis and loss of all reflexes in the left upper extremity and dissociated sensory disturbances in the left arm, left side of the neck and trunk, extending slightly into the trigeminal region above and into the two upper lumbar segments below. There was also loss of sense of position in the fingers of the left upper extremity; the scrotal reflexes were weak and the epigastric reflexes could not be elicited. The roentgenogram showed the bullet to be on a level with the clavicle about 7 cm. from the median line. It were well to bear in mind, moreover, as Muskens has suggested, that a bullet whizzing through the canal without grazing the cord may, in addition to the intradural hemorrhage or localized serous meningitis, bring about changes in the cord itself not unlike those occurring in Caisson's disease. The prognosis, therefore, should not be too sanguine in such cases until we have had more experience with wounds caused by the high velocity bullet. In two cases operated upon by Muskens, the bullet had passed by the side of the cord, but in each case the dura and cord were found to be intact despite the fact that the patients suffered from complete flaccid paralysis and almost complete loss of reflexes. These symptoms may have been due to the intradural hemorrhage and the increased intraspinal pressure, as slight improvement followed the exploratory laminectomy in both cases, but it is quite possible that during the passage of the bullet grave changes may be wrought in the cord similar to the air bubbles which are formed in the gray substance in Caisson's disease.

After careful microscopical examinations in cases of concussion, Holmes' observations were as follows:

> The vessels are found engorged, and there are generally punctiform hemorrhages, especially in the gray matter. The most striking change, however, is the edematous swelling of the most affected segments, with either diffuse or focal necrosis and softening, which, at least in the cases that have been examined microscopically, has been most pronounced in that part of the cross section nearest the

point of impact. In these areas there may be complete destruction of all the functional elements, but more usually only a proportion of the fibers have disappeared, while the myeline sheaths and axis cylinders of others are swollen. Focal softenings also occur in the gray matter, but are usually unrelated to the hemorrhages which this frequently contains. There is, often, however, some softening and disintegration of the tissue, as well as degeneration of the nerve cells, around these hemorrhages.

The distant lesions in cases of concussion are similar to those found associated with direct and contusion injuries, but they are often very marked in relation to the changes found at the site of maximum damage. Scattered hemorrhages, irregular foci of necrosis, and softening and cavity formation occur, but the most pronounced feature is the extensive parenchymatous changes that often extend over four or five segments in either direction. These consist in the swelling of fibers, either isolated or in groups, in the midst of tissue which is otherwise normal or only slightly edematous; as a rule the axis cylinder is more swollen and the myeline sheath surrounds it as a distended and attenuated ring, but in places the sheaths are more affected, and are often broken up. The disappearance of these swollen fibers and the partial disintegration of the neuroglia leave vacuoles and round or oval cavities in the white matter and give it a reticular or sieve-like appearance. There are also often considerable histological alterations, either degenerative or chromatolytic, of the nerve cells at some distance from the level of the injury, but these are found most commonly where the tissue is edematous.

It is very common in these cases of grave medullary disturbances without bone lesions to find marked inflammatory changes in the meninges, abnormal collections of fluid and adhesions. The occurrence of circumscribed serous meningitis and arachnitis serosa spinalis has been especially emphasized by Marburg and Ranzi and by Rumpf. In a case reported by Rumpf the autopsy revealed marked inflammatory changes in the meninges and cord. The patient, a reservist 30 years of age, had complete motor and sensory paralysis of the lower extremities, of the bladder and rectum, weakness of the patellar reflexes and decubitus. The x-ray showed that the bullet had lodged just to the left of the tenth thoracic vertebra. Since both motion and sensation partially returned in the legs within a few days, operation was not considered; the patient died, however, and autopsy revealed marked inflammatory changes in the meninges and cord. In one of Goldstein's cases in which there was no bone lesion, the bullet being found below the left shoulder blade, autopsy revealed no injury to the thoracic vertebrae external to the dura. Upon opening the latter, however, the bullet was found to be closely adherent to the cord at the level of the fourth thoracic segment. Indeed, there was a marked constriction of the cord at that point.

It were well to bear in mind that not infrequently the symptoms point to a lesion considerably above or below the site of the bullet or the point at which it came in contact with the vertebral column, as has been commented by Westphal, Finkelnburg and others. The vibratory force transmitted to the cord by the high velocity bullet may cause lesions not unlike those just described and degenerative changes at points quite remote from

the original point of contact, as in disseminated myelitis, or it may give rise to an arachnitis and abnormal collections of fluid which extend considerably above or below the point at which the bullet entered the back.

Occasionally, as we have already mentioned, the bullet may sink from its original position in the spinal canal, but the symptom-complex may still indicate a lesion at the first level.

There is still another group of cases in which the clinical picture and the autopsy findings show grave involvement of the spinal cord, but in which there has been neither a direct nor an indirect injury to the spinal column. The sudden changes in atmospheric pressure caused by the explosion of the modern shells and grenades are responsible for these grave changes in the spinal cord. The victim falls to the ground immediately with all the signs of a partial or complete transverse lesion, and autopsy reveals the various macroscopical and microscopical changes mentioned just above. Netousek has recently reported the occurrence of hematomyelia in a soldier who was lying at some distance from an exploding grenade. There was no external injury, but the soldier became unconscious immediately and was completely paralyzed. In a week he was able to move slightly the upper extremities and the right lower extremity. There was severe motor paresis with spastic phenomena in the left leg, exaggerated patellar reflexes, ankle clonus, Babinski and Oppenheim signs. The epigastric and cremasteric reflexes were absent on the left. There was complete loss of pain and temperature sense in the right leg and on the right side up as far as the territory supplied by the fourth thoracic nerve, with a narrow hyperalgesic zone above this area. The roentgenogram was entirely negative and there was no sensitiveness to pressure in the back. Under electrical treatment and iodids there was a slight improvement.

Symptomatology and Diagnosis.—The *symptom-complex* following gunshot wounds of the spine and spinal cord differs little from that caused by other injuries of the vertebrae and cord. There is usually more or less edema and ecchymosis of the soft tissues about the external wound, which is circular in most instances, although the ricocheting bullets often make very jagged, irregular wounds. Frequently the signs of injury to the vertebral column, such as tenderness on pressure over a spinous process or pain on pressure upon the head, may be absent. Under such circumstances the bullet may reach the spinal canal through the interarcual spaces and the vertebral processes may thus escape injury. Many cases of gunshot wounds of the spine are associated with severe pain due to irritation of the posterior roots and of the meninges.

The cord symptoms vary according to the nature, extent and seat of the lesion. The partial lesion, in the form of a more or less typical Brown-Séquard syndrome, and the complete transverse lesion are both common, and vary in their expression according to whether the pathological changes

take the form of a contusion, laceration or hemorrhage, or a traumatic degenerative process due to concussion. In some cases the symptoms may indicate the involvement of a circumscribed area near the periphery of the cord, as when the tip of a bullet or spicule of bone impinges upon the cord surface. This happened in the following case of Perthes:

A gunshot wound of the spine at the level of the second cervical vertebra, with paralysis limited to the muscles of the hand and foot. The removal of the bullet was followed by complete recovery.

The patient was shot in the neck, the wound of entrance being just above the angle of the right mandibular bone. There was complete paralysis of the muscles of the right hand and paralysis of the extensor muscles of the right foot and toes. There were no sensory disturbances. The patellar and the plantar reflexes were exaggerated. The bullet was revealed in the roentgenogram between the

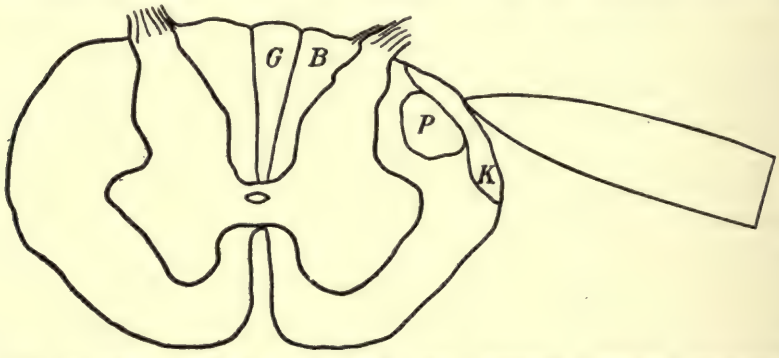


FIG. 210.—DIAGRAM OF CROSS SECTION OF CORD, SHOWING BULLET IMPINGING UPON LATERAL CEREBELLAR TRACT. (After Perthes.)

P, Lateral pyramidal tract; *K*, lateral cerebellar tract; *G*, column of Goll; *B*, column of Burdach.

second and third cervical vertebrae. The seat of the bullet excluded the possibility of injury to the roots supplying the brachial plexuses. The symptoms were attributed to pressure upon the lateral pyramidal tracts (Fig. 210). That the paralysis of the muscles of the hand should have been more complete than those of the foot may be explained by the relative position of the tracts: those for the hand are situated more to the side than those for the foot. The limited extent of the paralysis must be accounted for by the fact that only the tip of the bullet had come in contact with the cord (Fig. 210).

Operation. Local anesthesia. Resection of the arches of the second and third cervical vertebrae. There was but little blood in the spinal canal, but free cerebrospinal fluid. The bullet was found with its point penetrating the dura. The wound to the dura, which was so small that the cord could not be seen, was closed with sutures. Sixteen hours after the operation there was some restoration of motion in hand and foot, and in the course of the next few days restoration of function was almost complete.

The clinical picture accompanying these lesions, with its variations according to the level involved, has been previously described (*vide* p. 409)

and, therefore, I shall not dwell at length on them here. Emphasis is being laid upon using the extent of motor paralysis rather than the upper border of the sensory disturbances for localization of the lesion in cases of gunshot wounds. This has been done for some time when isolated muscles or groups of muscles of the upper or lower extremities were affected, but little attempt has been made at interpreting palsy of the muscles of the trunk for this purpose. Holmes believes this to be of great value in making a topographical diagnosis of lesions of the six lower thoracic segments. For example, if the eleventh segment be involved, we find paralysis of the lower portion of the external and internal oblique with bulging of the iliac regions, while the whole rectus abdominalis contracts when the patient raises his head or coughs. If the ninth segment be affected, the lower part of the rectus abdominalis is paralyzed, while the upper part contracts vigorously. The condition of the intercostals is also very valuable in the localization of lesions, particularly of the upper thoracic segments. By placing the finger over an intercostal space, the muscle will be felt to contract strongly on each inspiration if it be not paralyzed. This is a valuable guide, since each intercostal muscle receives its nerve supply from the corresponding thoracic root.

While accurate *charting and interpretation of the sensory disturbances* is an aid in making a topographical diagnosis, these are by no means infallible, particularly in cases of incomplete or unilateral lesions, chiefly because of the decussation of the sensory fibers and their oblique course within the cord. It should be borne in mind, moreover, that the decussation occurs quickly in the midthoracic region, gradually becoming slower as we go upward. Certain phenomena, such as the lowering of the upper level of anesthesia and the escape of early reappearance of sensation in the caudal region, have given a new insight into the arrangement of the sensory fibers of the second order, as they ascend through the ventrolateral column. According to Holmes they indicate "a lamellar arrangement in which the fibers that carry any specific form of sensation from successive dorsal roots lie in series; and as there is a general law that the longer ascending fibers lie nearer the periphery of the cord, those that convey impressions from the lower spinal roots are probably placed lateral to those that have later reached the contralateral side. The escape of the sacral root areas would therefore indicate a lesion that involves only the more mesial fibers of the sensory path, while an anaesthesia disproportionately low in relation to the level of the spinal injury would suggest a local destruction of its more lateral fibers. When it becomes possible to correlate the exact histological changes in these cases with the results of careful clinical examinations, definite conclusions on the exact course of the fibers that carry various forms of sensation from different regions of the body will be possible."

Holmes has found the disturbance of *deep sensations,* particularly the

sense of vibration, a help in those cases of lesions limited to the dorsal columns in which the sense of touch and pain is unaffected. In these cases the vibrations of a heavy tuning fork are not recognized below the level corresponding to the injured segment. Since the thorax may act as a sounding box, the fork must be applied in this region only to folds of the skin which have been raised. On the other hand, in cases of unilateral lesions in which pain and temperature sensation are completely lost, those forms of sensation conducted by the dorsal columns are often intact. In some cases homolateral astereognosis has been found to be present when tactile sensibility was otherwise unaffected. In incomplete transverse lesions anesthesia to pain and temperature is almost invariably present, while tactile sensation may be preserved. Above the twelfth thoracic segment, unilateral lesions take the form of a more or less typical Brown-Séquard syndrome (*vide* p. 421). Head and Thompson's observations indicate that pain and temperature impressions pass through the opposite lateral column, "muscle sense" through the homolateral column, while tactile impressions have two pathways—one through the opposite lateral and one through the dorsal column of the same side.

As indicative of lesions between the second cervical and second thoracic segments are the symptoms which result from disturbances of the cervical sympathetic: the miosis or inequality of the pupils, the narrowing of the palpebral fissure, the enophthalmos, the diminution of tear secretion, flushing of the face (especially after shaving) and diminution of sweat or relative dryness of the skin on the affected side.

An interesting syndrome in lesions of the lower part of the cervical enlargement is represented by slow pulse, subnormal blood pressure and scanty secretion of urine. The temperature in some cases is lower than can be registered by a clinical thermometer, the pulse rate from thirty to fifty, rising or falling with the rise and fall of temperature, and the urinary secretions sometimes entirely suppressed.

As an occasional symptom in lesions of the lower cervical and three upper thoracic segments, Collier mentions persistent shivering of the face, neck and shoulders without any sense of coldness on the part of the patient, although a rise in temperature is a much more common accompaniment of lesions of the cervical cord.

In one case observed by Leva the involvement of certain medullary centres was expressed in the paralysis of the recurrent laryngeal nerve, in a unilateral atrophy of the tongue and difficulty in swallowing. Bilateral and unilateral paralysis of the diaphragm points to a lesion of the cervical cord as far down as the fifth cervical segment.

As significant of lesions of the thoracic segments of the cord, I remind the reader of abdominal distention in some cases associated with muscular rigidity and more or less persistent vomiting. The association with the latter of girdle pains and hyperesthesia of the skin between the ensi-

form cartilage and the umbilicus would indicate a lesion of the sixth, seventh, eighth and possibly ninth thoracic segments and reminds one of the gastric crises of tabes and the relief afforded by section of the posterior roots of the corresponding cord-segments.

Recently I have had under observation a patient with an acute inflammatory condition of the fifth and sixth thoracic segments in which polyuria has been a striking symptom, the patient, a boy of sixteen years, voiding for several weeks from 150 to 200 ounces in urine per day. In all probability the polyuria is due to arrest of function of the vasoconstrictor fibers of the kidney.

Disturbances of all *reflexes,* both deep and superficial, should be carefully studied. Of the superficial reflexes, the cremasteric and abdominal are most easily lost. A lesion in the abdominal segments may often be localized by observing the segment at which the abdominal cutaneous reflexes are absent. Babinski's sign is seldom present in complete transverse lesions during the first two weeks. In very severe cases there will be no movement of the toes, in the slightly less grave ones there may be a simple flexion of the great toe. Holmes has found that when a flexor movement gives place to an extensor movement between the seventh and twentieth day, improvement almost invariably ensues. Both knee and ankle jerks are absent at first in all severe cases. The knee jerks are the first to return, but never earlier than two or three weeks after the injury.

FIG. 211.—X-RAY SHOWING BULLET BETWEEN THE SECOND AND THIRD CERVICAL VERTEBRÆ, IN A VERTICAL PLANE CORRESPONDING TO THE REGION OF THE SPINAL CORD. (After Perthes.)

The position of the bullet corresponds to the level of the cord lesion.

While the *roentgenogram* is often of so much value in confirming the presence and exact location of a bullet or splinter of bone that careful x-ray studies should never be omitted, it is by no means infallible. In a case operated upon by Rumpf in which the symptoms indicated a complete transverse lesion, but in which the roentgenogram was negative, it was found at operation that the cord had been smoothly sectioned by the bullet, which was lodged in the arch of the eleventh thoracic vertebra. However, the x-ray should at least demonstrate the pressure of a bullet near, if not in, the canal (*vide* Fig. 211), and without x-ray evidence it is quite

possible to overlook a bullet, even though it be within the spinal canal. The figure shows the bullet between the second and third cervical vertebrae, in a vertical plane corresponding to the region of the spinal canal. The situation of the bullet corresponded to the level of the cord lesion. It must also be remembered that the motor and sensory phenomena often point to a lesion somewhat above or below that caused by the bullet itself.

FIG. 212.—LESION OF THE CAUDA EQUINA, SHOWING THE BULLET EMBEDDED IN THE ROOTS AT THE LEVEL OF THE SECOND LUMBAR VERTEBRA. (After Latarjet.)

Another case shows very emphatically the mistake of depending entirely upon the symptoms for diagnosis, and performing an operation without resorting to a roentgen examination.

The patient was hit while bending over in setting up wire entanglements. The point of entry of the bullet was 4 cm. to the right of the median line at the level of the second sacral vertebra and there was no point of exit. The patient suffered excruciating burning pains and the motor and sensory symptoms indicated a lesion

at the level of the fourth lumbar vertebra. A laminectomy performed at this level failed to uncover the projectile and further exploration was prohibited by the condition of the patient. Death occurred the following day and subsequent autopsy showed that the bullet had followed an oblique ascending course and had lodged in the roots of the cauda equina at the level of the second lumbar vertebra (Fig. 212).

FIG. 213.—ROENTGENOGRAM OF GUNSHOT WOUND WITH FRACTURE OF TWO VERTEBRAL BODIES. (Courtesy of Dr. Charles F. Riley.)

While the evidence of skeletal injury is very marked, there was no evidence whatsoever of cord involvement.

However, the roentgenogram is of little help in ascertaining the *extent or nature of the cord lesion,* and herein lies the crux of the situation both from the standpoint of prognosis and treatment. Are we dealing with a complete and irreparable transverse lesion or with only a partial lesion capable of amelioration, if the source of irritation or compression be removed or the increased pressure relieved? There is still much uncer-

tainty regarding these points. According to Bastian and Bruns, the loss of the deep reflexes is a positive indication of a complete transverse lesion. Some of the recent cases of gunshot wounds are proving, however, that this is not an absolute proof; hence, intervention should not be absolutely contra-indicated simply because the deep reflexes are absent. In a case operated upon by Muskens, in spite of the loss of the deep reflexes and complete flaccid paraplegia, there was no reaction of degeneration after

FIG. 214.—GUNSHOT WOUND OF THE SPINE. (Riley.)
Missile *in situ*, without any evidence whatsoever of an injury to the spinal column, the patient presented the clinical picture of a complete transverse lesion of the cord.

nine days had elapsed; the operative findings and the postoperative course proved that a complete transverse lesion had not existed; and again in a case seen by Holmes in which a piece of shell casing lacerated the cord in the lower part of the fourth thoracic segment and downward through the next three lower segments, feeble knee jerks could be obtained after the fifteenth day.

I recently examined two x-ray plates of gunshot injuries of the spine from the war zone—in the first plate (Fig. 213) two vertebral bodies appeared shattered but there had been no injury to the cord, while in the other (Fig. 214) the plate showed no evidence of fracture or foreign body

within the canal, but the case represented all the symptoms of a complete transverse lesion. Fracture of the spinous processes or depressed fractures of the laminae are not easily brought out by the x-ray and even with stereoscopic pictures it is not always easy to determine whether a bullet lies within or without the spinal canal. However, roentgenograms should be taken routinely in the hope of eliciting the site of a bullet or the presence of a dislodged fragment, and to determine if possible whether the bullet is within the spinal canal.

Symptoms of a complete transverse lesion are by no means indicative of a physical interruption in continuity. As we have already seen, operative findings and autopsy examinations reveal in many cases an uninjured dura and a cord which is macroscopically normal. The variations in pressure, caused by the bullet whizzing through the canal without even grazing the dura, and transmitted to the cord through the cerebrospinal fluid or the blood, and the membranes and septa, result in microscopical changes and give rise to a symptom-complex indicative of a transverse lesion. Therefore, in giving a prognosis and in weighing the question of intervention, one must consider carefully both the x-ray findings and the various clinical phenomena, as no one sign alone can be taken as an absolute criterion of the extent or gravity of the damage to the cord.

Operative Treatment.—The treatment of gunshot wounds of the spine is a complex problem. The momentous question in most instances is whether an exploratory laminectomy is indicated and, if indicated, how soon after the injury it should be performed. A judicious decision in these matters must take under consideration many factors: the facilities for performing the operation, the experience of the surgeon, the distinction between gunshot wounds in civil and military practice, the presence of a complete transverse or an incomplete transverse lesion, the presence or absence of bullets or fragments within the vertebral canal, open or closed wounds, direct injury of the cord, as compression, laceration, contusion, or indirect injury as commotion or concussion.

Generally speaking, the problems of military and civil practice differ in these particulars: in civil practice the injuries are due almost invariably to bullets, not always of large caliber, and the wounds are frequently not infected; in military practice, shrapnel and shell are the source of injury quite as frequently as bullets, where there is greater damage to the soft tissues as well as to the skeleton, and infection must always be taken into account. In military practice, too, there are many instances of cord injury such as concussion or commotion, often unaccompanied by injury to skeleton or by flesh wounds.

Indirect Injuries.—Let us consider first indirect injuries to the cord, concussion or commotion, those due to an explosion in the vicinity, to the impact of a bullet against the vertebral column, without direct impact on the cord, or to the passage of a bullet adjacent to, but not involving,

the vertebral column. In this category, it must be borne in mind that the interference with cord function may at first be quite as pronounced as when the cord is actually severed by a bullet. At the outset the picture may be one of complete transverse lesion, even though the lesion be the result solely of concussion. Under the circumstances, early operation is clearly contra-indicated. Should, however, the symptoms persist without amelioration, an exploratory laminectomy under suitable circumstances may be considered within the limits of propriety, on the grounds that the persistence of symptoms may be the result of hemorrhage or an undetected injury of the vertebral column. Be it remembered here, as in other parts of this discussion, that the clinical evidence of a total or complete transverse lesion does not signify an irreparable injury to the cord. In fact, so often has the interpretation of the signs of a total lesion been found misleading, that surgeons are rather prone to seize this as a valid argument in favor of frequent recourse to exploratory laminectomy. Along these lines Armour puts the question: Are there any symptoms by which we can in a reasonable time determine beyond a doubt that we are dealing with a case either of complete transverse section or of pure concussion? If there is not, then should we not be urged to give our patient the benefit of an operation which experience shows neither materially endangers his life nor adds to his discomfort, but actually lessens his pain? It will at least allow us to determine the exact nature and extent of the lesion and to place the cord under the most favorable conditions for recovery of function, if recovery is possible.

Direct Injuries.—Direct injuries to the cord by bullet, shrapnel, or bone splinters the propriety of a laminectomy admits of little discussion. This general proposition with certain qualifications has been subscribed to quite generally by neurologists and surgeons alike who have had opportunity for abundant observation during the European war. While it may be true of the individual case, as it is no doubt of a large number, that the damage to the cord is accomplished at the time of the accident and that the persistence of symptoms is the result, not of continued compression, but of the intramedullary changes in the cord due to the original impact, an exploratory laminectomy should be performed whether the picture be one of a complete or incomplete lesion.

One may assume that if the injury be due to shrapnel, the cord is more apt to be hopelessly damaged than when injured by a bullet. But after all the nature of the cord lesion is largely a matter of conjecture, and there is a temptation to take the position, endorsed, as it is by Oppenheim, that operation is indicated even in cases of total transverse lesion, for, while in most cases the operation will be fruitless, there is nothing to lose and perhaps something to be gained. In twenty operations for gunshot injuries of the spine Guleke found the cord completely crushed in ten. But while only five of the twenty cases recovered from the operation, three

of these would have died in the opinion of Guleke, had not fragments of bone or bullets been removed by operation.

Time of Operation.—As to the time of operation, some urge immediate operation, while others advise waiting three to five weeks, or until the likelihood of recovery seems remote. Whatever may be the view of the individual surgeon, it is at least true that no operation should be undertaken until the patient has recovered from shock, and not until the patient reaches a base hospital from which he will not have to be transferred until the fractured spine has been well repaired. Authorities agree that secondary changes are more likely to develop as a result of early transportation and therefore absolute rest is advisable in the convalescent period if the condition offer any prospect of useful recovery. Marburg advises waiting four or five weeks or until the clinical picture continues unchanged, but to this general rule I can see very serious objections. The continued pressure of the foreign body will in time give rise to connective tissue formation, which by contractures and adhesions would impair the function of the cord, and the processes of degeneration might within a period of four or five weeks be so well established that the subsequent removal of bullet or bone splinter would not be followed by restoration of function. Furthermore, in delay there is the added risk of decubitus, cystitis, or meningitis, any one of which may determine a fatal issue.

In military practice, the selection of the time for operation depends upon considerations which would not affect the civilian surgeon. The performance of a laminectomy should be undertaken only when every facility is afforded for operating under the strictest aseptic precautions, when time and experience permit of a thorough examination and critical study of the clinical findings before the operation is undertaken, when there is an adequately equipped x-ray apparatus, and finally in a hospital so far to the rear that a reasonable time may elapse before the patient need be transported. Under these conditions at least several days may elapse before the operation can be performed. Perthes found that a delay of five to ten days was not inconsistent with complete restoration of function, but there are cases on record when function was recovered even after the lapse of a much longer period. That little is to be gained by surgical intervention months after the accident is illustrated by the following case:

The patient, a young man, *aet.* 21, on my service at the University Hospital, had been accidentally shot in the lower cervical region by a .22 caliber firearm almost two years before his admission. He sank to the ground paralyzed but entirely conscious and free from pain. At first there was quadriplegia with paralysis of the bladder and rectum, but gradually some return of function followed in the arms, and he was able to hold his urine for about an hour. Fairly free movement of the right shoulder was possible and the motor power of the right upper limb was decidedly better than the left. All four extremities were very spastic, in the lower limbs the adductors being particularly so. Sensation for touch, pain and

temperature was impaired in all four extremities and on the trunk up to the third rib; but the distal parts of the extremities were much more affected than the proximal portions. The reflexes were greatly exaggerated in both upper and lower extremities and the Babinski reflex was pronounced on each side. The x-ray demonstrated that the bullet had fractured the lamina of the fourth cervical vertebra and was located about in the midline.

Operation.—The spinous processes of the fourth and fifth cervical vertebrae were removed and one-half of the laminae of the respective vertebrae removed and the dura opened opposite the fifth cervical vertebra. Upon attempting to extend the incision over the fourth, adhesions between the dura and cord were encountered which had to be divided with sharp pointed scissors. This was finally affected and the bullet located embedded about one-half of its length in the substance of the spinal cord a little to the right of the median line. When it was extracted, a sharply defined cavity exactly conforming to the shape of the bullet was seen.

The ease with which the bullet was located and the facility with which it was removed made it a most favorable case for surgical intervention; and yet because of the delay, the processes of degeneration were already so complete that the removal of the bullet had little, if any, effect upon the patient's condition.

Roentgen Examination.—Always, before an operation is undertaken, the roentgenologist's report should be available. By the roentgenogram one should determine the precise location of the bullet, or, should none be present, the presence of a dislodged fragment usually in front of a fractured lamina. To determine whether the bullet is within the spinal canal and responsible for the cord symptoms, lateral and anteroposterior exposures should be made. Furthermore, as pointed out by Perthes, attempts at localization should not be made until the probable location of the bullet has been determined by the motor and sensory disturbances. The tube should be placed exactly over the suspected site of the bullet, since, if above or below, the shadow of the bullet upon the plate will be above or below its actual level with relation to the vertebral body. If the roentgenogram reveal the shadow of the bullet exactly in the middle of the shadow of the vertebral body at a level corresponding to the clinical evidence of the cord lesion, one may presume that the bullet is within the vertebral canal.

Contra-indications.—Having defined the conditions which indicate operative interference, we will state briefly the contra-indications. Frequently the spinal injury is associated with pulmonory or abdominal complications. Naturally the existence of a pneumonia or perforating wound of the abdomen would deter the surgeon from any operative investigation of the spinal injury, no matter how serious it may be. For example, in a series of twenty spinal injuries Noehte records six deaths in nine operations as a result of injuries elsewhere; four of these had a hemothorax and two, abdomen injuries. Shock and collapse should, of course, be included among the positive contra-indications to early operative interference. Later on, should infection be established, adjacent to the field of operation, or should there be meningitis, either of these conditions should

be regarded as prohibitive; and at a still later stage, when the signs of cord degeneration are evident, when decubitus, cystitis, or pyelitis already presuppose an incurable condition, all thought of surgical procedure should be dismissed.

Included among the later indications for operation are the symptoms attributable to the pressure of an organized exudate, or callus, of a traumatic pachymeningitis or of a circumscribed serous meningitis, and in not a few instances the principal indication for operation is persistent and intractable pain.

Technic.—As already indicated, accurate *localization* of the bullet or of the injury to the vertebra is a requisite preliminary to a laminectomy. To identify the relationship of the bullet to a given vertebra, before the x-ray is taken, a strip of metal, or a small coin, should be fastened to the skin over a spinous process, which is indelibly marked with caustic silver; or, as Hull suggests, under local anesthesia, a silver wire suture may be introduced at the side of a spinous process of the suspected vertebra. If the x-ray tube is not placed directly above the bullet, the relationship between the bullet and the metal strip or coin will be distorted. This was illustrated in a case in which the bullet was believed to be on a level with the body of the twelfth thoracic vertebra and the coin was placed over the spinous process of the eleventh. When the roentgenogram was taken, the tube was not directly over the bullet, and in the plate the shadow of the coin appeared at a lower level than that of the bullet (Fig. 215). At the operation a search was made for the bullet above the level of the coin. The bullet was not to be seen and had the search not extended to a lower level, the bullet would not have been found. Once the foreign body is localized, one should determine whether its location corresponds to the seat of the cord lesion as deduced from the physical examination.

Local anesthesia is unquestionably safer than ether narcosis in all operations upon the spinal cord, more particularly in injuries of the cervical segment. The technic has already been described. The incision should be planned to include the spinous processes and laminae of at least three vertebrae, the one at the level of the lesion and one vertebra above and below. After removal of spines and arches, a careful inspection is made of the underlying dura. Blood clots, discoloration, or induration of the dura are presumptive evidence of the site of the injury. In some cases the bullet may be found without the dural sac, or the cord pressure may be due to the compression of a broken lamina. With the removal of one or the other, and when the dura appears uninjured, one must consider the propriety of opening the dura, but owing to the possibility of infection along the track of the missile, it is wiser to leave the dura intact, unless from the signs of tension and marked discoloration the presence of a subdural clot be suspected. It must not be assumed, when the dura appears uninjured, that the cord has escaped. Impact of a foreign body upon the

membranes may seriously damage the cord without lacerating the membranes; but, even under these circumstances, unless there be a subdural hemorrhage there is nothing to be gained by opening the dura, since the damage to the cord itself cannot be repaired.

Failing to find the bullet without the dura after a careful inspection on all sides, the dura must be opened and the search continued. After

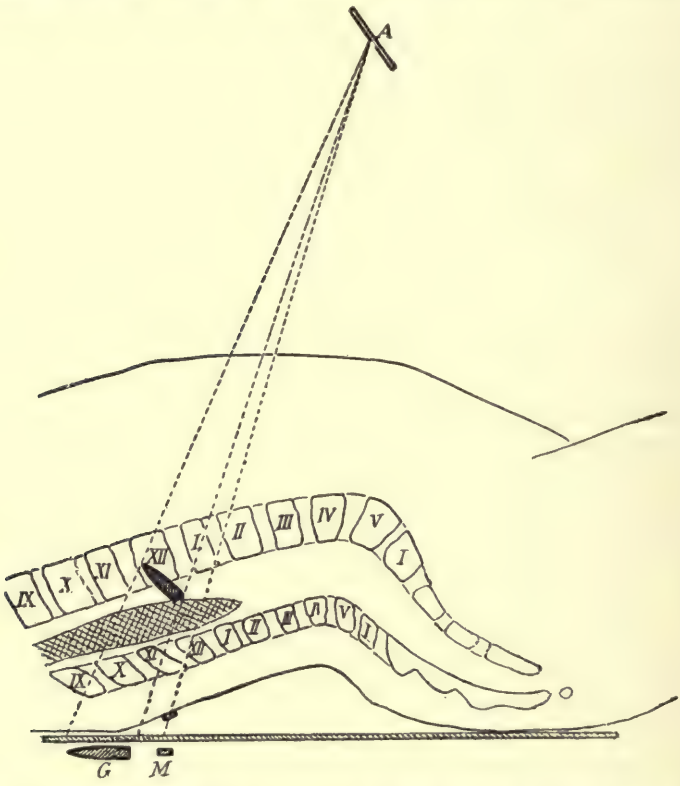


FIG. 215.—DIAGRAMMATIC SKETCH SHOWING THE RELATIVE POSITION OF THE X-RAY TUBE, THE BULLET AND THE COIN, AND THE DISTORTED RELATIONSHIP OF THESE UPON THE PLATE. (After Perthes.)

G, Shadow on the plate of the bullet imbedded in the twelfth cervical vertebra; *A*, x-ray tube; *M*, coin.

the removal of bullet or splinter of bone, lacerated or punctured wounds of the cord and in some cases severance of the roots may be revealed; but the futility of cord or root suture in the restoration of function is so well recognized that attempts at repair by suture, though occasionally practiced, are unwarranted. There seems to be a difference of opinion among surgeons with extensive military experience as to whether the dural incision should be closed in all cases. In deciding this question the surgeon must take into consideration two factors: one, the presence or absence of

infection in the bullet tract, and the other, the condition of the cord. As to the former, every precaution must be taken to guard against infection of the subarachnoid space, and if the wound be septic, closure of the dural incision is the safer course to pursue. In the absence of infection should the cord be so swollen and edematous that closure of the dural incision exerts undue pressure, a condition of exceptional occurrence, the dural incision may be left unsutured. On general principles, leaving the dural incision open as a routine practice should be condemned.

FIG. 216.—BILATERAL SECTION OF THE CAUDA EQUINA BY A PIECE OF SHRAPNEL. (Lévy and Cotte.)

Periradicular hematoma; destructive lesion of the cord. Note the perforation of the dura on the anterior aspect of the cord between the roots in the center of the lesion.

Prognosis.—The mortality of gunshot wounds of the spine during the Civil War (1861-1865) was 55.5 per cent, in the Anglo-Boer War (1899-1901) 58 per cent, while in Exner's series in the Balkan War (1912-1913) it was 93.8 per cent, an unusual mortality. Although it is impossible at this date to make more than a preliminary statement of the results of gunshot wounds in the European war, I have been able to gather together the reports of 175 cases in which the mortality may be estimated at between 50 and 55 per cent. Perhaps in the final analysis this estimate may have to be revised, since with the more extensive employment of heavy artillery and high grade explosives one would rather have anticipated a mortality rate for the European war higher than any of the preceding. Generally speaking, shrapnel injuries are much more apt to cause complete and irreparable lesions of the cord, in contrast to the bullet injuries which have given the largest number of favorable results. It is interesting to note, in this connection, that, of the sixteen cases recorded by Perthes, the three shrapnel injuries caused a

complete transverse lesion, while in only one of three bullet wounds was the lesion complete.

The mortality rate implies in most instances the more or less immediate effect of the injury with or without operation, and not the late consequences of decubitus or urinary sepsis. Usually the higher the lesion the graver the injury; thus gunshot wounds of the cervical cord should be the most fatal, and those of the cauda equina the least. However, in the European war, contrary to his expectations, Marie found in his service at the Salpêtrière that injuries of the cervical cord were less grave than those of the thoracic or lumbar region. In the cervical region the canal is relatively larger and the cord not so likely to be compressed by the passage or lodgment of the bullet, while wounds in the thoracic region are more often accompanied by injuries to the lung. Out of eighteen patients with paralysis of both arms and legs, under the care of Marie, only five had died at the time of his report. Five gradually recovered the use of their limbs in a few months and one was able to run. The outlook after gunshot wounds of the caudal region is perhaps brighter than those of any other segment of the cord. In some cases severed roots have been sutured and recovery of function has been attributed in part to this.

Comparing the results of these injuries in civil with those of military practice, I may quote from a series of 170 cases from civil life (Prewitt, Nast-Kalb, Haynes) in which the mortality was 61 per cent, a mortality higher than that in military practice.

It does not appear that the death rate is influenced by operative procedure, if one compare the rate of those that died after operation and those that died without operative intervention. No deductions, however, should be drawn from these figures, since in the selection of cases for operation the desperately injured and apparently hopeless cases would have been excluded. In my collection of 175 cases in the European war the respective mortalities of the laminectomized and non-laminectomized cases was 41 and 65 per cent, and in civil practice, 60 and 62 per cent. Of individual groups taken from surgical experience of the present war the following summary illustrates the immediate results of surgical interference:

	TOTAL	DIED	RECOVERED
Frangenheim	25	9	16
Noehte	9	2	7
Marie	18	4	14
Marburg	12	4	8
Guleke	20	15	5
TOTAL	84	34	50

The causes of death were for the most part shock, pneumonia, meningitis, and grave injuries to the cord. Thus in ten out of fifteen deaths

in Guleke's series the cord was completely crushed; in five cases sepsis of one form or another was the cause of death. The ultimate results depended naturally upon the character of the injury, the degree of damage to the cord, whether the conditions were such as could be relieved by surgical procedure. In the latter class more particularly were the injuries to the cord by compression of bullet or bone splinter, the removal of which resulted in more or less complete recovery of function. These, however, were the exceptional cases, and here and there most gratifying results were obtained. The following cases were selected as typifying the results obtained after the removal of the bullet from various levels of the cord.

Case 1.—(Symonds.) Removal of shrapnel bullet. Private ——, aged 29, was hit by a shrapnel bullet in the back on August 2nd, 1916. Eight days later, on the 10th, he was admitted to the Royal Victoria Hospital, Netley. There was an entrance wound over the eighth left interspace four inches from the posterior median line, but no exit wound. There was retention of urine and incontinence of feces, no voluntary movement in the lower limbs, though muscular twitchings were seen at times and the legs were noticed to move unknown to the patient. There was reaction of degeneration in the muscles of the legs, but very slight in those of the thighs. The knee jerks were absent; pin prick sensation was lost on the front and outer aspects of both thighs; it was retained on the outer side of the legs and dorsum and soles of the feet, and in this last situation there was hyperesthesia. The scrotum retained sensation. X-rays showed a shrapnel bullet slightly above and to the left side of the spinous process of the eleventh dorsal, with evidence of fracture of this vertebra. After a few days the retention disappeared, a catheter being no longer required; the urine passed every five to ten minutes, accompanied by straining and some pain. When I examined this patient before operation I found a spastic condition of the limbs. At times he was seized with severe pain in the legs, and cried out so that it disturbed others. He had also abdominal pain with flatulence, and lay mostly on his side with knees drawn up.

Operation, August 27th, 1916.—From the position of the bullet as shown by the x-ray it might have been deeply buried in the bone. The symptoms pointed to a severe injury to the cord with progressive destruction, and not to a complete lesion. An incision was made in the median line and the muscles detached from the left side only. The bullet was found lying between the laminae of the eleventh and twelfth dorsal vertebrae. The eleventh lamina was broken, several fragments being driven into the canal. The spinous process and the right lamina, not being broken, were left. The opening into the canal was enlarged sufficiently to give a full examination and ascertain the absence of further fragments or of projecting bone. The dura was uninjured and was not opened. The muscles were sutured, the wound closed and a primary union resulted. No immediate or striking result was observed after the operation, and only gradually did patient acquire control over the bladder and rectum.

Three months after operation his condition is as follows: He can retain urine for three hours, and longer during the night, and can, when the need comes, wait a little time. He has control over the rectum, but owing to the approximation of the thighs and tenderness in the back he cannot use a bed pan, nor is he able to sit up on a commode. He has pain in both legs and below the ribs on both sides as well as in the abdomen. He is free from pain for several days at a stretch, and then may require a sedative for two or three nights. He can feel cotton-wool and pin-prick over the whole of the right lower limb, but not in the left thigh, while he

can feel below the knee. He can move the toes and slightly the ankles on both sides, and he has some voluntary movement in the muscles of the thighs. For the most part, however, both lower limbs are in a spastic condition, the knees held tightly against one another.

CASE 2.—(De Lapersonne.) Oculosympathetic syndrome; fragment of ball in the sixth cervical vertebra. Removal and disappearance of symptoms.

Paralysis of the right upper and lower extremity and visual disturbance on same side. Gradual improvement in lower extremity, but movements are less active and vigorous than on the opposite side. Sensibility is preserved. There are no trophic disturbances. Patellar reflexes exaggerated, Babinski present, no clonus.

In upper extremity, movements more difficult. Extension of fingers impossible and passive movements are painful. Hand edematous. Sensation is diminished in entire forearm. Abundant sudation of the palm of the hand and atrophy of the forearm. R. E.: slight ptosis. Enophthalmus with diminution of the palpebral fissure and slight myosis. Syndrome of Claude Bernard-Horner. Pupillary reflexes are well preserved. Ophthalmoscopic examination shows a very acute papillary stasis with peripapillary edema and tortuous veins. The field of vision is not notably reduced. Vision of the left eye is almost normal.

Roentgenogram showed a foreign body at the level of the right lamina of C_6, and a bony fragment compressing the cord. Thus the paralytic oculosympathetic symptoms were accounted for by lesion of the seventh and eighth cervical segments.

Operation three months after the injury. Median incision from C_4 to T_1. Section of the spinous processes, opening of the vertebral canal at the level of C_6. Fragment of shrapnel ball was immediately found.

The oculosympathetic syndrome disappeared the day after the operation. Five weeks later the following condition was noted: Oculosympathetic syndrome has not reappeared. The papilla is less prominent; the veins are voluminous. The visual acuity is equal. No modifications of the visual field. The trophic disturbance of the upper extremity has completely disappeared.

CASE 3.—(Whiteford.) Shrapnel bullet in the spine; paraplegia; laminectomy; partial recovery.

Bullet wound at the level of the first lumbar spine, one inch to the right of the middle line. Instantaneous paralysis of both legs. Anesthesia: right side, complete from iliac crest to toes; left side, from knee to toes, with diminished sensation in thigh. Paralysis: right thigh and leg, complete; left thigh and leg, very slight voluntary movement of toes only. Reflexes: right leg absent; left leg present, but diminished. Urination involuntary; defecation unconscious. The roentgenogram showed a shrapnel bullet in body of the first lumbar vertebra. Operation ten days after injury. Spine exposed through an eight-inch vertical incision, the center of the incision being opposite L_1. The laminae and spinous process of L_1 were removed. The bullet had passed through and comminuted the right lamina. The theca was opened, and the cords of the cauda were found intact. The theca and cord were retracted to the patient's left and the bullet removed from the posterior surface of the body of L_1. Because of sepsis from the bullet track, the small opening in the theca was not sutured.

Twenty-four weeks after the operation: Control of the bladder is complete. In the right leg, during the last seven weeks, sensation has been unaltered; in the muscles above and below the knee, both in front and behind, there is slight, but quite definite, voluntary contraction. The patient is beginning to get about on crutches.

CASE 4.—(Michaëlis.) Surface wound to left of midline at the level of the fourth cervical vertebra. At first paralysis of both upper and lower extremities, but not of the bladder. Paralysis of the right side gradually diminished spontaneously,

slight weakness of the right arm remained. X-ray showed lesion of C_4 at union of arch to body. Bullet itself was lodged behind the horizontal ramus of the left maxilla. No improvement in paralysis of left side.

Laminectomy one month later. The laminae of the third, fourth and fifth cervical vertebrae removed. (The bullet had penetrated the margin of the cord in the left side. This defect in the cord was closed with a catgut suture.) Gradually the paralysis of the left leg diminished from below upward. Four weeks later the paralysis of the leg had so diminished that the patient could walk with only slight support. Paralysis of left arm only slightly improved.

CASE 5.—(Baudet.) Penetrating wound of the spinal canal by a shrapnel ball. Compression of the cord. Paralysis of the lower extremities. Laminectomy. Extraction of the bullet. Progressive improvement in paraplegia.

Operation three weeks after the injury. The spinous processes of the sixth, seventh and eighth thoracic vertebrae were resected, and the laminae of the seventh and a part of the sixth. The bullet, which was found outside the dura mater severely compressing the cord, was removed and the wound closed with drainage. The paralysis gradually improved, and ten days after the operation the patient was able to get about.

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CHAPTER VIII

SPINAL TUMORS

Despite their comparative rarity, tumors of the spinal cord, of the meninges and of the vertebral column are constantly claiming more and more attention from the neurologist and the surgeon, the opportunities for surgical service are becoming greater and the outlook ever more encouraging. The progress of surgery in this field is particularly astounding when one considers that a little more than twenty-five years have elapsed since the first operation was performed by Sir Victor Horsley for the removal of a spinal tumor, a condition which up to that time had been considered hopeless. The patient was a man forty-two years of age, who had suffered for three years from intercostal pains. Four months before operation, the lower extremities became weak, and gradually there developed paraplegia and anesthesia, which became complete up to the level of the sixth or seventh thoracic roots, accompanied by severe clonic spasms in the legs and by paralysis of the bladder and rectum. A fibromyxoma (Fig. 217) at the level of the third and fourth thoracic vertebrae was removed; one year later the pain had practically disappeared, the patient had gradually recovered both motor and sensory functions and could walk without difficulty.

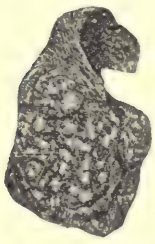

FIG. 217.—A FIBROMYXOMA, NATURAL SIZE. (Horsley and Gowers.)

The first case of successful removal of a tumor from the spinal cord. Operation by Horsley in 1887.

In the comparatively short space of time since this epoch-making operation, an ever increasing number of spinal tumors have been correctly diagnosed and either wholly or partially removed; and in a few cases where radical operation has not been practicable, decompressive laminectomy or resection of the sensory roots has been resorted to as a palliative procedure. The functional end results have become better and better, partly because of our ability to localize the growths earlier and with greater precision than heretofore and partly because of the improved operative technic which is now followed. Over 18.1 per cent of the cases operated upon have been reported as cured, and in 19.3 per cent the improvement has been marked (*vide* Tables XXVII to XXXII). Though the percentage of complete recoveries is still very small, it is, nevertheless, encouraging when one considers that without surgery the prognosis is hopeless. More-

over, every case in which the diagnosis has been confirmed by operation helps to establish a more accurate basis for localization and for more successful operations in the future. Only a short time ago, the ability to localize tumors was so limited that the operation was undertaken with apprehension and uncertainty, while at the present time operation may be performed with a reasonable certainty of finding the tumor and, in many instances, of removing it. Until very recently, the attention given operable conditions of the brain, especially tumors, was quite out of proportion to that devoted to corresponding lesions of the cord. Experience is proving that the cord is more favorable for surgical interference, the conditions to be relieved quite as distressing and the prospect of relief greater, since a larger proportion of spinal tumors are operable. Spinal tumors are more rare than those of the brain, as shown by Schlesinger's classical record of the findings at 35,000 autopsies, where the ratio of tumors of the cord to those of the brain was about 1 to 6, but this fact certainly should not deter us from furthering the development of spinal cord surgery. Even since the new era began in 1887, interest in spinal tumors has been more or less vacillating, but stimulated by the progress in spinal localization, through the researches of Sherrington, Head, Déjerine and others, a new enthusiasm has been awakened during the past decade. The relation between the various cord-segments and their roots to the cutaneous segments on the one hand, and their muscular terminations on the other, is now so definitely established that we are able to draw fairly definite conclusions as to the location of the lesion. But a knowledge of the processes of degeneration of nervous tissue, of the exact course and relation of the conducting tracts and of the location of the various reflex arcs and automatic centers is also essential to an intelligent decision as to the feasibility of operation. Much has been accomplished in these directions, though there are still many gaps to be filled in by clinical observations and experimental research.

Our experience has proved that the spinal canal can be opened at any height from the atlas down to the lowest portion of the sacral region with comparative safety, although the mortality in these two regions is higher than at other levels. However, Söderbergh and Akerblom have recently reported the complete removal of an endothelioma of the highest cervical segment. By the adoption of certain precautions and certain measures preventing shock, we have found that the removal of tumors at high levels need not be approached necessarily with apprehension even in patients of advancing years, as in the following case:

Recovery following the removal of an endothelioma at the level of the third cervical vertebra from a patient sixty-four years of age, with restoration of function.

The patient, a woman, *aet.* 64 (File No. 31342), was admitted to the University Hospital, February 21, 1916. Her past medical and family history was negative. History of present condition: in November, 1914, she noticed a dull, aching pain in the right shoulder below the clavicle extending to the insertion of the deltoid muscle. This pain was increased by coughing and sneezing and radiated posteriorly. In July, 1915, she began to have numbness in the fingers of the right hand, which gradually extended upward to the wrist. By August, 1915, the motor function of the right hand had become affected and this increased to a practical paralysis. Numbness and tingling were first noticed in the toes of the right foot in August, 1915, and shortly afterward patient complained of awkwardness in moving the right lower extremity. By October, 1915, she noticed paresthesia in the left hand and arm and a girdle sensation. The latter, she thought, made it difficult for her to void her urine when in bed. All of these symptoms grew progressively worse. Because of the circumscribed distribution of the pain, the patient had been admitted under a diagnosis of intercostal neuralgia.

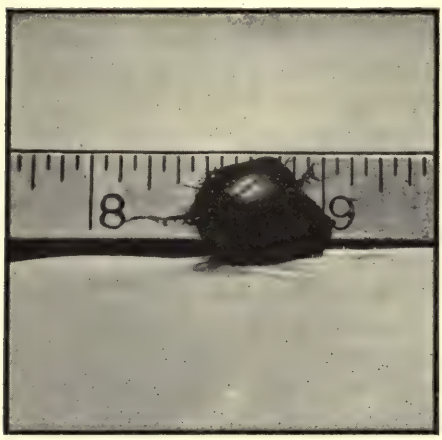

FIG. 218.—PHOTOGRAPH OF AN ENDOTHELIOMA REMOVED FROM THE CORD AT THE LEVEL OF THE THIRD CERVICAL VERTEBRA. (Length in inches.)

Physical Examination. The cranial nerves were normal. There was slight tenderness at the level of the fourth and fifth cervical spines, well demonstrated by forcibly pressing down the head. The grip of the right hand was almost absent and of only moderate degree in the left hand. Voluntary movement of the right upper limb was very slight and passive motion was painful. There was possible some movement of the fingers of the right hand, a slight degree of flexion at the right elbow and some elevation of the right shoulder. Some spasticity was present in the right upper limb. Motion in the left upper limb was free and easy. The biceps and triceps reflexes were exaggerated on both sides. The patellar reflexes were exaggerated on both sides with an abortive patellar clonus on the right. Oppenheim and Babinski reflexes were distinct on the right; on the left the Babinski reflex was uncertain and the Oppenheim reflex not obtained. Both lower limbs were spastic. There was a marked reflex of defense on the right and some indication of it on the left.

In testing for sensation it was noticed that the patient tired easily and that her attention flagged; therefore, her answers were accepted with caution. Sensation for heat and cold and touch was probably preserved over the entire body. The senses of position and passive movement were disturbed in both hands and greatly impaired in the toes of the right foot, but probably not in the toes of the left foot.

At lumbar puncture there was registered a pressure of 6 mm. of mercury. Wassermann examination of cerebrospinal fluid was negative. Roentgenological examination of the cervical vertebrae was negative. A diagnosis was made of tumor of the spinal cord at the level of the fifth cervical segment and an operation was advised.

Laminectomy, February 26, 1916. The spinous processes of the second, third, fourth and fifth and the laminae of the third, fourth and fifth cervical vertebrae

were removed. There was no visible pulsation synchronous with respiration or the pulse. Upon pricking the arachnoid the cerebrospinal fluid spurted out about five centimeters above the level of the opening and about 30 c.c. of fluid escaped from the dural sac below the opening. The tumor was found on the level of the third lamina on the right side of the cord, covered by a membrane, which was divided, thereby disclosing more sharply a differentiation between the tumor and the cord substance. The tumor, an endothelioma, took origin from the dura at the right anterolateral aspect of the spinal canal (Fig. 218). There was no difficulty in detachment until the base was reached and its enucleation and elevation were

FIGS. 219, *a* and *b*.—PHOTOGRAPHS OF PATIENT AFTER REMOVAL OF EXTRAMEDULLARY TUMOR OF THE CERVICAL CORD, SHOWING RECOVERY FROM PARALYSIS IN THE RIGHT UPPER EXTREMITY. (University Hospital, File No. 31342.)

accomplished without trauma to the cord. It was possible to disengage the mass without sacrificing any nerve roots save the posterior root of the third cervical segment on the right. The operation was unusually free from bleeding until the detachment of the growth from its base in the dura; this caused continuous, slight oozing which was controlled by a sliver of muscle tissue. The dural incision was not closed until bleeding had ceased. Before closing the wound the patient was given a pint of normal saline solution by enteroclysis and fifteen minims of camphorated oil hypodermatically. At the beginning of the operation the blood pressure was 120 mm.; it rose in a few minutes to 145 mm. and dropped later to 105 mm., the lowest point reached. At the conclusion of the operation the blood pressure was 120 mm. and the pulse 134.

The patient gained daily in power and the sensory condition steadily improved. Three weeks after the operation it was recorded that she could get her right hand to her face, a movement she had not been able to make for five months (Figs. 219, *a* and *b*). Four weeks after the operation she was able to stand on her feet and

walk a few steps (Fig. 219, *c*). Since this time her progress has been entirely satisfactory. She was discharged from the Hospital April 2, 1916, and the reports, one year after operation, showed no return of symptoms.

We will discuss later the limitations and the results of intramedullary procedures. In cases of extramedullary tumors, we may hope for excellent functional results if the continuity of fiber tracts has not been seriously disturbed. Out of 182 tumors taking their origin in the meninges, roots and cauda, 37 cases have been reported with complete recovery from paralysis and with disappearance of trophic symptoms and 45 as greatly improved (*vide* Table XXVIII). Even in cases of long-standing compression, there has been a gradual reëstablishment of motor and sensory function in some instances, although the earlier the operation is performed, the better the prognosis.

FIG. 219, *c*.—PHOTOGRAPH OF PATIENT AFTER REMOVAL OF EXTRAMEDULLARY TUMOR IN THE CERVICAL REGION, SHOWING RECOVERY OF FUNCTION IN THE LOWER EXTREMITIES SUFFICIENT TO ENABLE THE PATIENT TO STAND AND WALK UNAIDED. (University Hospital, File No. 31342.)

The symptom-complex of tumors of the cord and of lesions simulating tumors, has become the subject of a most searching analysis. Oppenheim, Schultze, Déjerine, Nonne, Spiller, Mills, Bruns, and many others have collected a vast amount of clinical material. Nevertheless, in spite of our ever-widening experience, there remain many baffling and perplexing problems; to solve these there must be the closest coöperation between physiologist, neurologist, surgeon and pathologist, a most careful study of the evolution of the clinical expression of the disease, a comparison of these notes with the findings at the operating table, in the pathological laboratory, or at autopsy, and finally the correlation of all these observations with the postoperative course and the functional results. With the information gained from these several sources, we may hope for earlier and more accurate diagnoses in cases that otherwise might have been overlooked or allowed to go unrecognized until the condition had become hopeless.

According to custom, we use the term *spinal tumor* in its broadest sense, embracing not only tumors of the cord itself, pure intramedullary growths, but also extramedullary tumors, having their origin in the meninges or vertebrae, together with those of the conus and cauda equina. We have made origin the determining factor for division into the four follow-

ing groups: the intramedullary, the extramedullary, the caudal and the vertebral; these groups differ from one another to a more or less marked degree in symptomatology, in evolution and in prognosis. The extramedullary variety may be either extradural or intradural, but as the prognosis is much better if the growth be intradural, and the possibility of extirpation much greater, an attempt should always be made to differ-

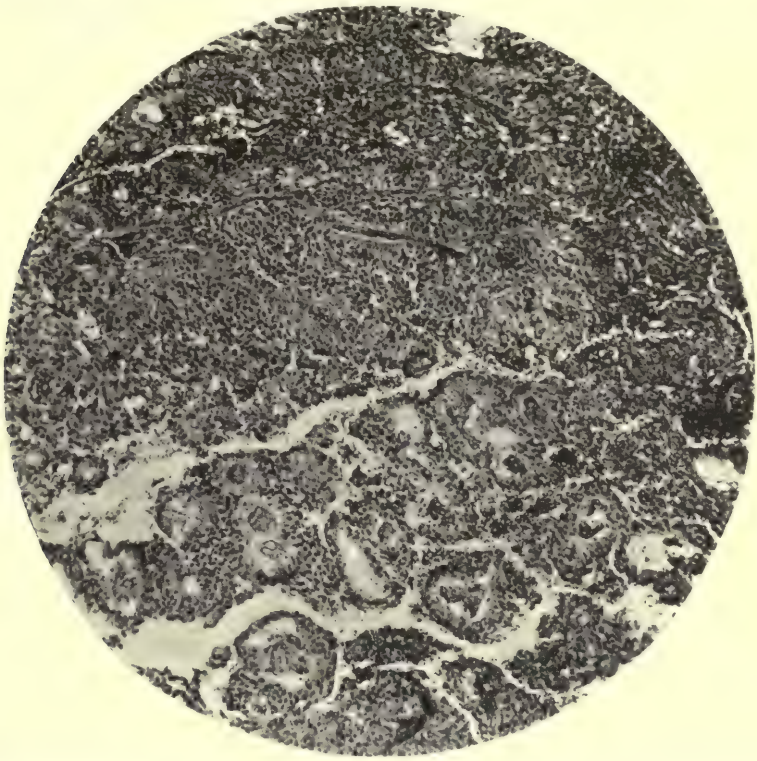

FIG. 220.—PHOTOMICROGRAPH OF AN EXTRAMEDULLARY PERITHELIAL ENDOTHELIOMA OF THE CORD. (Bovaird and Schlapp.)

entiate even between these two types of extramedullary lesions. Pathologically, we have included, besides the various types of actual tumors found in the spinal cord and its adnexa, three inflammatory reaction processes, namely, tubercles, gummata and cysts. We have left for a later chapter the consideration of the various forms of circumscribed meningitis which often give rise to symptoms closely simulating tumors of the cord or of the meninges.

Incidence.—Tumors of the spine and the spinal cord, primary or secondary, are among the rarer affections of the cerebrospinal nervous system. In a comprehensive review of the literature, we have found 330 cases in which an operation has been performed: 152 meningeal, 58 verte-

bral, 36 intramedullary, 30 caudal and 54 cases in which the origin was not stated. It is interesting to note that in Schlesinger's report of the 35,000 autopsies in *Das Allgemeine Krankenhaus* of Vienna during 18 years, 135 spinal tumors were found, 0.38 per cent of the number of autopsies, and 2.06 per cent of the total number of tumors. Of these, 91 (67.4 per cent) had developed in the vertebral column, while 24 (17.7 per cent) arose in the meninges or roots, and 20 (14.8 per cent) in the cord itself. In addition to this number there were sixteen vertebral tumors which in no way involved the vertebral canal. Out of 3,617 autopsies at the Boston City Hospital, an intravertebral growth was found in 4 instances (Knapp).

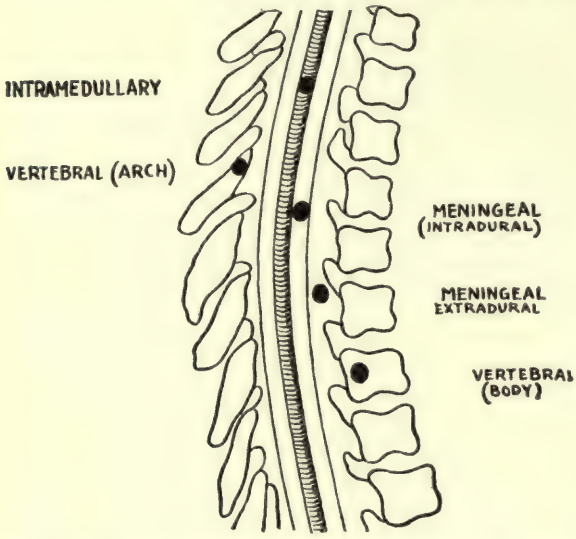

FIG. 221.—DIAGRAMMATIC SKETCH TO INDICATE THE VARIOUS POINTS OF ORIGIN OF TUMORS OF THE SPINAL CORD, MEMBRANES AND VERTEBRAL COLUMN. (Sagittal plane.)

Etiology.—The etiology of tumors of the spinal cord is as obscure as that of tumors elsewhere. While we frequently find mention of a trauma, concussion or a blow upon the spine in the anamnesis, very often the onset of the symptoms antedates the trauma. Thus, while the injury may have accelerated the growth of the tumor and hence the development of the symptoms, it has not been the causative factor in most instances. According to Mills, when a predisposition does not exist, a fall is more prone to produce osteoma, fibroma or sarcoma than any of the other varieties. That a fall may cause a metastatic tumor to invade the spine appears probable, and Bruns has reported a case of primary sarcoma of the prostate which metastasized to the lower thoracic vertebrae after a fall upon the back. Nevertheless, this is but an instance of acceleration of growth and metastasis, not incitation. Bovaird and Schlapp have recently reported a case in which an extramedullary endothelioma (Fig. 220) was removed from a college student one year after an injury received in a football game. Spasticity and numbness in the lower extremities and severe pain in the spine developed immediately after the trauma. Though there is in these cases a chronological relation between trauma and tumor, the part played by trauma as a causative factor must continue

to be an open question, and the etiology of spinal tumors, as of brain tumors, still remains a matter of conjecture.

Topographical Relations of Tumors.—Tumors involving the spinal cord and its adnexa may arise in the vertebrae, in the meninges or roots, or in the cord itself (Figs. 221 and 222); they may be situated at any height in the vertebral column or on any aspect of the cord, though they are more prone to certain locations than to others. In our collection of 330 cases, almost half were extramedullary with their origin in the meninges; only one tumor in seven took its origin from the vertebrae, while, according

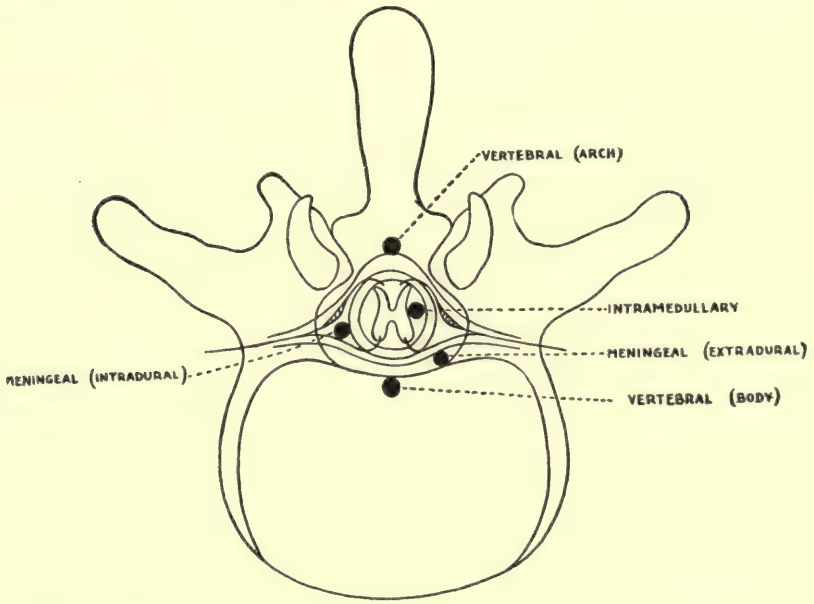

FIG. 222.—DIAGRAMMATIC SKETCH TO INDICATE THE VARIOUS POINTS OF ORIGIN OF TUMORS OF THE SPINAL CORD, MEMBRANES AND VERTEBRAL COLUMN. (Horizontal plane.)

to Schlesinger's report of the autopsy findings in 135 cases and various other collections based on the findings at autopsy rather than at operation, vertebral tumors are the most frequent, the meningeal somewhat less common, and the intramedullary of still rarer occurrence. The discrepancy between the statistics based on operative findings and those based on autopsy records is to be accounted for by the fact that extramedullary tumors of meningeal origin are the most favorable for operation and hence fewer come to autopsy. Therefore, although meningeal tumors may not be of common occurrence when we consider spinal tumors as a whole, nevertheless they are the most important from the operative point of view. Of 330 spinal tumors for which an operation was performed, we found:

TABLE I

45 arising in the vertebrae
13 invading the vertebrae
55 extradural } extramedullary
97 intradural }
30 arising in the roots and cauda
36 intramedullary
54 location not stated.

330

Of 135 cases in Schlesinger's table which came to autopsy there were:

TABLE II

Vertebral origin		91	
Subdural space extending outside		4	
Dura	external	4	11
	internal	5	
	not stated	2	
Arachnoid		1	
Dura or arachnoid		2	
Pia mater		1	
Nerve roots and cauda		5	
Intramedullary		20	
		135	

As readily seen in the foregoing table, meningeal tumors, besides arising from the inner or outer surface of the dura, occasionally take their origin from the arachnoid or the pia. But as the space in which meningeal tumors may develop, whatever their origin, is comparatively small, their origin makes little, if any, difference in the character of the symptoms, inasmuch as very soon not only the meninges, but the cord and roots, are affected (Fig. 223).

TABLE III

TOPOGRAPHICAL OCCURRENCE OF TUMORS

Location	Extramedullary		Intramedullary	Vertebral		Caudal	Not Stated	Total
	Intradural	Extradural		Primary	Secondary			
Cervical	28	9	15	7	1	..	13	73
Cervicothoracic	6	1	..	..	..	..	1	8
Thoracic	61	34	17	23	7	..	30	172
Thoracicolumbar	..	2	..	..	..	..	2	4
Lumbosacral	2	7	1	15	5	30	7	67
Not stated	..	2	3	..	..	..	1	6
TOTAL	97	55	36	45	13	30	54	330

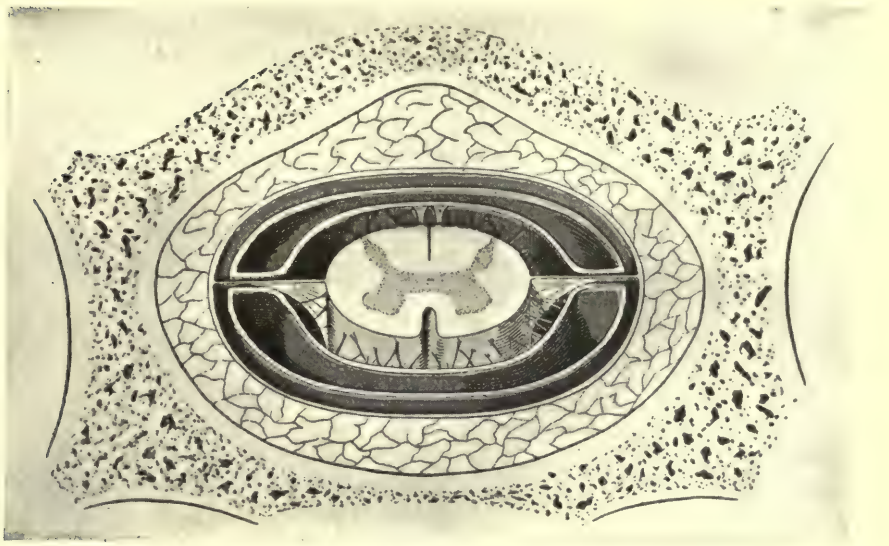

FIG. 223.—SCHEMATIC REPRESENTATION SHOWING RELATIONS OF THE SPINAL MENINGES TO ONE ANOTHER AND TO THE VERTEBRAL CANAL. (Villiger.)

While spinal tumors may occur at all levels of the cord, the thoracic region is most frequently invaded, as will be seen in the accompanying table (Table III). This may be attributed, in part at least, to the fact that there are more segments here than in other regions of the cord.

Potel and Veaudeau after reviewing carefully the literature, give practically the same results as to location (Table IV).

TABLE IV

Thoracic	52 per cent
Cervical	20 per cent
Lumbosacral and caudal	28 per cent

And the following is a table compiled by Oustaniol from 86 cases:

TABLE V

Upper cervical region	3		
Middle " "	5	18	
Lower " "	7		
Cervicothoracic "	3		
Upper thoracic "	11		
Middle " "	6	32	
Lower " "	15		
Thoracicolumbar "	3	5	
Upper lumbar "	2		
Filum terminale		17	
Cauda equina			
Diffuse	7		7
Situated in canal without connection with meninges	7		7

While the majority of tumors seem prone to develop on the posterolateral or posterior aspect of the cord, they occasionally appear, as in a case which came under the author's observation (*vide* p. 531), on the anterior or anterolateral surface. Oustaniol gives the following report as to the relation of the tumor to the cord in 76 cases:

TABLE VI

Anterior surface of cord	7	
Posterior " " "	18	
Lateral " (right)	9	19
" " (left)	10	
Anterolateral (right)	3	7
" (left)	4	
Posterolateral (right)	3	9
" (left	6	
Diffuse	8	
Partly surrounding cord (dorsal)	3	
" " " (outside of dura)	5	

The relation of the tumor to the cord in the cases we collected was very similar (Table VII).

TABLE VII.

Location		Anterior	Antero-lateral	Pos-terior	Postero-lateral	Not Stated	Total
Extramedullary	Intradural	6	9	31	31	6	83
	Extradural	..	2	11	11	8	32
Intramedullary		1	1	16	3	11	32
Roots and cauda		2	..	5	2	10	19
Vertebral	Primary	9	3	5	2	6	25
	Secondary	2	..	3	2	2	9
Not stated		..	..	..	..	130	130
TOTAL		20	15	71	51	173	330

In conclusion it may be said that operable spinal tumors are largely extramedullary, intradural and on the posterior or posterolateral aspect of the cord.

Pathology.—There must be more or less doubt as to the nature of the tumor until it has been revealed either by operation or autopsy, although the rapidity of its growth, as evidenced by the progress of the symptoms, may

be some indication as to the histological character of the lesion. When the symptoms develop very slowly, the tumor is more likely to be a fibroma, a psammoma, or a lipoma of extramedullary origin, while a rapid course almost invariably implies a malignant growth.

The great majority of spinal tumors, especially those of extramedullary origin, develop slowly, compressing the cord most often from the side, though sometimes from the back or front, and occasionally completely encircling it. The cord may be reduced to one-quarter its normal size at the site of the tumor, while both above and below it may be even larger than normal. In spite of prolonged and extreme degrees of pressure, degenerative changes in the cord are sometimes entirely lacking, or are present only in the form of a slight marginal myelitis, and when pressure is removed, the cord will often rapidly assume its normal proportions. Where the compression is severe, this myelitic margin is more extensive, sometimes with small hemorrhages into the gray matter, and when of long duration, degeneration with complete destruction of the columns may occur. This is particularly frequent with vertebral carcinoma.

Spinal tumors, whatever their character, seldom attain great horizontal dimensions, chiefly on account of the limited space in which they develop, but partly because the damages they inflict upon the cord are incompatible with life. The majority of tumors do not measure more than 2.5 cm. in length, though Elsberg removed a caudal tumor 15 cm. long, and the one removed by Lexer measured 17 x 2.4 x 2 cm. Edema of the membranes is frequently met with in these cases, and very often there are abnormal collections of cerebrospinal fluid above or below the tumor, under varying degrees of tension. The majority of clinicians have observed collections of fluid (meningitis serofibrosa) above, but some have noted an abnormal quantity below the tumor. Krause feels that, inasmuch as the passage of the fluid is necessarily interrupted in cases of intradural tumors of any size, the fluid is forced cephalad, resulting in increased tension above, and decreased tension below the tumor, and this view is entertained by many other observers. Söderbergh and Akerblom give an interesting case in which they found great tension below the tumor; it was that of a huge extramedullary but subpial endothelioma, weighing 9 grams and reaching to within 12 cm. of the atlas. In this instance, the high location of the growth without doubt had some effect on the tension of the cerebrospinal fluid. Raven in his recent study of the diagnostic value of examination of the cerebrospinal fluid in cases of compression of the spinal cord, has tabulated the findings in 25 cases of spinal tumors. In 12 cases there was no mention of the degree of pressure, in 5 it was noted as remarkably increased, in 1 as slightly increased, and in 7 as normal.

In arranging the pathological data in our series of 330 cases, we have followed the classification and terminology which has recently been recom-

mended by Mallory. This classification is based upon a differentiation of the distinct types of tumor cells, of which Mallory gives fifteen. The ending *blastoma* has been added to the name of each one of these types, and applied to all tumors having their origin in that particular variety of cell. Thus, the term *fibroblastoma* includes fibroma and fibrosarcoma. But in addition to these simple tumors, there are numerous mixed tumors "due to the proliferation of cells of an earlier embryonic type which are capable of differentiation into two or more of the simple adult type cells" (Mallory), for example, fibro-endothelioma, or fibromyxoma. These mixed tumors have been classified according to the predominant type of cell, whenever possible.

FIG. 224.—SARCOMA ON THE ANTERIOR ASPECT OF THE SPINAL DURA AT THE LEVEL OF THE SECOND AND THIRD LUMBAR SEGMENTS. (Courtesy of Dr. William G. Spiller.)

A word of explanation is needed in regard to the use of the term *sarcoma*. It has formerly been used to include all malignant growths of a non-epithelial nature. Now it is applied to rapidly growing tumors, particularly of the first four types: fibrosarcoma, myxosarcoma, chondrosarcoma and osteosarcoma. The term *carcinoma* is restricted to malignant new growths of an epithelial nature. However, despite the fact that in our table we have tried to classify the sarcomata in the group to which they seem to belong, there were a large number of cases in which this was impossible. It, therefore, seems pertinent to insert a brief paragraph on sarcomata in general, including all malignant growths of non-epithelial origin.

Psammoma is also not considered as a special type of tumor, but classified, whenever possible, according to the type of its component cells, not according to some chance calcified product therein found. In some instances, it has been impossible on account of the lack of pathological details to reclassify the sarcomata and psammomata; hence a considerable number appear in the group marked "unclassified." We have also added

to Mallory's list the embryoblastomata, including teratomata and dermoids, and inflammatory reaction processes, such as tubercles, gummata and cysts. The accompanying table shows the relative frequency of the various kinds of tumors at the different levels (Table VIII).

Thus, we find the spinal cord and its adnexa the host for a great variety of tumors, though fibroma, fibrosarcoma and sarcoma are the most common. While spinal tumors as a whole occur most frequently in the

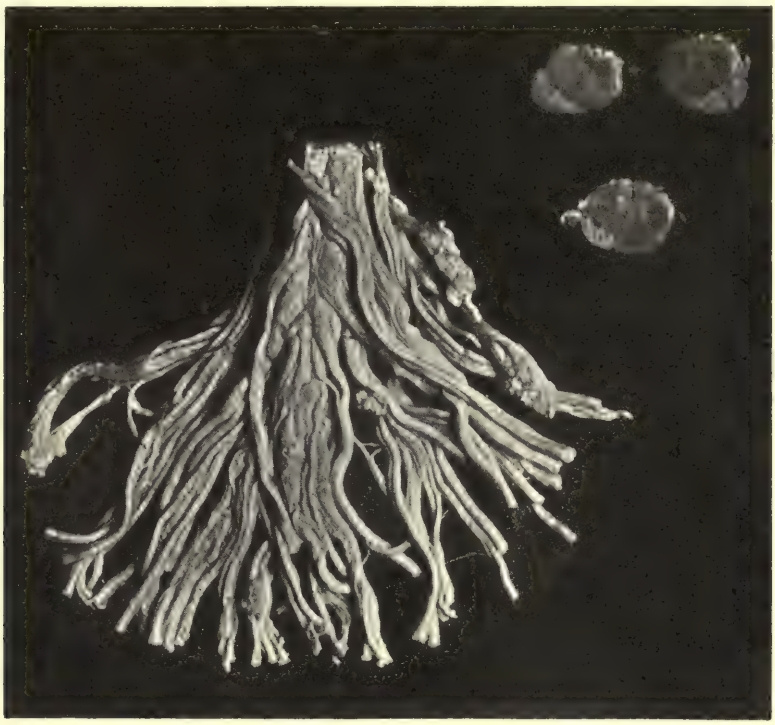

FIG. 225.—GENERAL SARCOMATOSIS. (Spiller.)

thoracic region, individual types may show a predilection for other levels. Based on the records of a large number of cases we find that tuberculomata, gummata and gliomata of intramedullary origin and extramedullary sarcomata, psammomata, fibromata and myxomata are the most common tumors found in the cervical region—myxomata and sarcomata, in the thoracic region, and tuberculomata and gummata of the cord and extramedullary sarcomata, lipomata, psammomata and hydatid cysts, in the lumbar region. A very brief sketch of the principal pathological features of the most common varieties follows.

Sarcoma.—Sarcoma may develop in the cord, meninges, or roots, and may be solitary or multiple. Those arising in the meninges seldom show any tendency to invade the substance of the cord, though they may seri-

TABLE VIII

CLASSIFICATION OF TUMORS ACCORDING TO LOCATION

Pathological Diagnosis	Cervical	Thoracic	Lumbosacral	Not Stated	Total
Fibroblastoma:					
Fibroma	8	13	4	1	26
Fibro-adenoma	..	1	..	..	1
Fibro-endothelioma	2	1	..	..	3
Fibromyoma	..	..	1	..	1
Fibromyxoma	..	3	1	..	4
Fibromyxosarcoma	..	2	..	..	2
Fibrosarcoma	10	10	9	..	29
Myxoblastoma:					
Myxoma	1	1	1	..	3
Myxolipoma	..	1	..	..	1
Myxosarcoma	..	..	1	..	1
Chondroblastoma:					
Enchondroma	2	3	1	..	6
Chondrosarcoma	..	1	1	..	2
Osteoblastoma:					
Osteoma	..	2	2	..	4
Osteofibrosarcoma	..	..	1	..	1
Lipoblastoma:					
Lipoma	2	..	1	1	4
Endothelioblastoma:					
(a) Hemangio-endothelioblastoma:					
Angioma	..	4	..	..	4
Angiofibrosarcoma	..	1	..	..	1
Angiolipoma	..	2	..	..	2
Angiosarcoma	1	1	2	..	4
(b) Lymphangio-endothelioblastoma:					
Lymphangioma	..	..	1	..	1
(c) Dural endothelioblastoma:					
Dural endothelioma	9	9	7	..	25
Lymphoblastoma:					
Lymphosarcoma	..	2	..	..	2
Myelomablastoma:					
Myeloma	1	1	1	..	3
Melanoblastoma:					
Melanoma	1	1	1	..	3
Glioblastoma:					
Glioma	5	9	2	1	17
Gliosarcoma	1	1	1	1	4

Pathological Diagnosis	Cervical	Thoracic	Lumbosacral	Not Stated	Total
Neuroblastoma:					
Neurofibroma	3	3	..	..	6
Neurofibro-angioma	..	1	..	..	1
Neurofibroglioma	..	1	..	..	1
Neurofibrosarcoma	..	1	..	..	1
Epithelioblastoma:					
Adenoma	..	3	..	..	3
Carcinoma	1	5	4	..	10
Embryoblastoma:					
Teratoma	..	..	1	..	1
Dermoid	..	1	1	..	2
Inflammatory-reaction processes:					
Tubercles	1	5	2	..	8
Gumma	1	..	..	..	1
Cysts	3	6	1	..	10
Unclassified:					
Sarcoma	10	41	15	..	66
Psammoma	..	13	..	..	13
Hydatid	..	6	5	..	11
Not stated	11	25	4	2	42
TOTAL	73	180	71	6	330

ously compress it (Fig. 224); they are rarely encapsulated, and often surround the cord. Sarcomata, however, have been known to start from nerve-roots, invading both meninges and cord. Unlike other tumors, they are frequently multiple (Fig. 225), and may be associated with sarcoma of the cerebellum or other organs. The isolated primary sarcoma of the meninges arises most often from the inner surface of the dura and, growing slowly and adapting itself to the dimensions of the canal, becomes

TABLE IX

SARCOMA OF MENINGES

Location	Intradural	Extradural
Cervical	10	4
Thoracic and lumbar	25	16
Conus and cauda	17	3
TOTAL	52	23

elongated rather than round and oval. Bérard has collected 75 cases of primary solitary sarcomata of the meninges, which were distributed in the canal according to the accompanying table (Table IX).

Primary isolated sarcoma of the cord is rare, and is sharply defined or encapsulated. Sarcomata frequently originate in the vertebrae, where they grow rapidly and compress the roots at a very early stage. Secondary sarcomata are fortunately extremely rare; they arise from a variety of sources, and rapidly involve both meninges and cord. Attention has been called by Harte, Spiller and others, to the fact that spinal sarcomata are not nearly so malignant as sarcomata elsewhere.

FIG. 226.—AN EXTENSION TO THE CORD OF CARCINOMA INVOLVING THE SEVENTH CERVICAL VERTEBRA, SECONDARY TO CARCINOMA OF THE MAMMARY GLAND. (Spiller.)

Carcinoma.—Carcinoma, since it is usually a metastatic growth and takes its origin from the vertebrae (Fig. 226), will be discussed fully in connection with vertebral tumors.

Tubercles.—Solitary tubercles have been most frequently found in the center of the cord; of relatively small dimensions, they take their origin in either the gray or white matter of the cord (Fig. 227), without necessarily changing its contour. They may also arise in the dura mater, compressing the cord. Out of eight cases of tubercular lesions in which an operation was performed, only three were limited to the cord itself. Either the cervical or lumbar enlargement is the seat in five out of six cases, although the thoracic portion of the cord may be involved, as in the following case:

A patient with pulmonary tuberculosis exhibited symptoms indicative of involvement of the spinal cord at the level of approximately the fifth thoracic segment. Laminectomy was performed and no extramedullary growth discovered. The diagnosis of intramedullary tuberculoma was tentatively made.

The patient, a man, *aet.* 54 (File No. 1067), was admitted to the Episcopal Hospital April 9, 1915. His father and one sister had died of tuberculosis. He had had typhoid fever at the age of 15, but denied alcoholic excess and venereal infection. In 1898 he had a "general breakdown" with tubercle bacilli in his sputum. His health had fluctuated for years during long periods spent at sanatoria.

The following was the chronology of his present condition: February, 1915, neuritis of the fifth, sixth and seventh intercostal nerves; March 13, numbness in the right thigh followed in a few days by numbness in the right leg, but neither difficulty in walking nor pain; March 20, numbness in the left leg followed by

numbness in the left thigh; April 2, slight pain and loss of power in left leg, which loss of power increased to absolute paralysis in twenty-four hours; April 5, slight loss of power in the right leg; April 8, complete paralysis in right leg. For three days prior to admission he was unable to pass his urine or to defecate. There was severe pain in the back, chiefly confined to the thoracic region and of a boring character. There was no pain in the lower extremities.

In both lower limbs there was a paralysis with increased reflexes but without ankle clonus or Babinski phenomenon. The sensory examination gave the following: hyperesthesia from the sixth to the eighth rib, more marked on the left than on the right. In this region there was analgesia and thermo-anesthesia. In the right lower limb there was analgesia, thermo-anesthesia and impairment of tactile sensation. In the left lower limb there was a small area of hyperesthesia on the inner aspect of the thigh but the rest of the limb was like the right. On April 10, 1915, a laminectomy was performed, the laminae of part of the second and all of the third, fourth and fifth thoracic vertebrae being removed. Careful inspection, after opening the dura, failed to discover any abnormality. The operation was done under local anesthesia (novocain, 0.5 per cent) without the patient experiencing pain except when the posterior roots were handled.

FIG. 227.—TUBERCULOMA ON THORACIC PORTION OF CORD. (Schlesinger.)

On April 15, it was recorded that the knee jerks were normal. As the localizing symptoms indicated a lesion in the neighborhood of the fifth thoracic segment, the absence of an extramedullary lesion would seem to indicate an intramedullary process, and inasmuch as the patient had for many years been subject to an extensive tuberculosis of the lungs, it was assumed that the cord lesion was an intramedullary tuberculoma.

Endothelioma.—Endothelioma is not so common in the spinal canal as in the brain (Spiller), but when so situated is usually small and of meningeal origin (Fig. 228). When multiple, endotheliomata take the form of small, disseminated nodules on the meninges and because of their wide distribution are not amenable to surgical intervention.

Fibroma.—Fibroma is one of the most favorable varieties for operation. It frequently takes its origin from the inner surface of the dura, compressing the cord, but not invading it (Fig. 229). It is firm in consistency, of slow growth and usually encapsulated. While it is found at all levels, according to Spiller, it is a little more common in the cervical and upper thoracic regions. Fibroma is sometimes found in combination with sarcoma.

Myxoma.—Myxoma is a rather common variety, though it is frequently combined with fibroma, lipoma or sarcoma. It is usually single, encapsulated, of slow development, and hence favorable for surgical in-

tervention. It is softer than fibroma, and indeed is often cystic. Though ordinarily rising from the inner surface of the dura, it never infiltrates the cord.

Lipoma.—Lipoma is rare except in association with spina bifida, and

FIG. 228.—AN ENDOTHELIOMA DRAWN IN SITU, BEFORE ITS REMOVAL FROM THE SPINAL CORD AT THE LEVEL OF THE THIRD CERVICAL VERTEBRA. (University Hospital, File No. 31342.)

The tumor appeared to take its origin from the dura in the lateral aspect of the spinal canal.

is most frequently found in the lumbar region. Its origin is almost invariably intradural, usually between the arches, and, in spite of its softness, may inflict serious pressure upon the cord. It is of slow growth, however, and readily removed.

Psammoma.—Psammoma, like fibroma, is a sharply defined tumor

and easily removed. It is of slow growth, so that recovery may be anticipated even after several years' duration. It is a hard tumor, round or oblong in shape, originating in the arachnoid or dura, and though it never invades the cord, it often causes serious alterations, sometimes even the destruction of an entire segment. It seldom becomes larger than an almond.

Gumma.—Gumma is usually a diffuse, non-encapsulated process, though sometimes sharply circumscribed, and does not lend itself to surgical intervention. While this growth originates in the meninges, as a rule, it may invade and destroy the cord tissue. Even if removal were possible, there would be very little hope of restoring function (Fig. 230).

FIG. 229.—FIBROMA BETWEEN THE FIFTH AND SIXTH CERVICAL SEGMENTS. (Spiller.)

Gliomata—Gliomata almost never originate in the meninges, but rather take the form of infiltrating tumors of the cord; they tend to diffuse more or less rapidly with corresponding enlargement of the segments involved and may extend practically the entire length of the cord. They are vascular, but rarely contain cysts as do gliomata of the brain. Occasionally, there are peripheral gliomata which affect only one-half the cord, and send prolongations into the roots, making it difficult to differentiate them from syringomyelia, as their peripheral limitations are not clear. They are most often found in the thoracicolumbar part of the cord.

Hemangioma.—Hemangioma of the central nervous system must be classed among the great rarities. Cobb has recently collected 7 cases from literature to which he has added one carefully studied case of his own. The genesis of the hemangioma is most likely to be found in a perverted growth of the endothelial lining of the larger blood vessels, particularly the veins; the vascularity of the growth may be diminished as the newly formed vessels become obliterated by the hyperplasia. The cases collected by Cobb were extremely vascular and showed a predilection for the lower part of the spinal canal.

Cholesteatoma.—Cholesteatoma in the spinal canal is of very rare occurrence and its origin is much disputed. The tumor is formed of many

layers of cells which may be epithelial or endothelial in type, interspersed with areolar tissue. At times there is a concentric arrangement of the cells, producing rounded bodies not unlike the pearly bodies of squamous

FIG. 230.—GUMMATA OF THE SPINAL CORD. (Schlesinger.)

carcinoma. Boström explains their histogenesis on the theory of epidermal inclusion at a period of embryonal life corresponding to the closure of the medullary canal. Robertson has recently reported the following most interesting case of cholesteatoma:

Consequent to a fall the patient developed weakness of the lower limbs and loss of bladder control, together with impairment of tactile, pain and temperature sense in the lower limbs. Laminectomy disclosed a long tumor, originating in the cord, which was successfully removed and proved to be a cholesteatoma.

The patient, a woman, *aet.* 19, was admitted to the Hospital, Dec. 28, 1914, with the following history: subsequent to a fall on her buttocks in 1910 she developed a weakness in the lower limbs and following this was troubled by an inability to start the act of micturition. She complained of a dragging sensation in the left leg which was followed by objective dragging, January. 1914. There was pain in the lower part of the back, especially on the left side. The patient was able to walk unaided but the gait was a modified steppage. The reflexes in the upper limbs were normal. Voluntary movement in both legs was preserved with exception of flexion of the ankle joint. Both patellar and Achilles tendon reflexes were absent and could not be reinforced. There was an impairment of tactile, pain and temperature sense in the lower limbs which was more of a delayed transmission than a very demonstrable decrease, though undoubtedly there was some analgesia.

An x-ray examination showed a sacralized sixth lumbar vertebra with failure of union of the posterior arches, also some coccygeal distortion.

A diagnosis was made of intraspinal tumor, extramedullary in location, chiefly on the left side of the cord and extending up as high as the third lumbar segment.

Laminectomy. The laminae of the tenth thoracic to the third lumbar vertebrae, inclusive, were removed, exposing the spinal cord from the twelfth thoracic segment downward. On opening the dura a large tumor was found filling the canal. The entire mass was finally delivered, no difficulty being experienced except at the lower third where the growth seemed to be in intimate relation with the cord from which it apparently had its origin. The tumor was 14 cm. in length and 2.5 cm. at its widest part (Fig. 231, A and B). Histologically, it proved to be a cholesteatoma. Eight days after the operation the patient was able to pass her urine voluntarily and since this time has never had to be catheterized. The control of the bowels was likewise restored. The right leg improved greatly, and, although there was still some foot drop in the left leg, the power had greatly increased. Her gait had become almost normal.

Hydatid Cysts and Cysticercus.—Hydatid cysts and cysticercus are rarely seen in this country, though of not uncommon occurrence in Germany, as may be seen in the statistics from *Das Allgemeine Krankenhaus.* They are of rapid development and at times compress the spinal cord, though the most serious complication is the involvement of the fourth ventricle or plugging of the aqueduct of Sylvius. Lumbar puncture frequently substantiates the diagnosis.

Age and Sex.—The statement has been made that spinal tumors are more prone to develop in the male than in the female, but our statistics do not show any great predominance of one sex over the other; there were 169 in males, 135 in females and 26 cases in which sex was not stated (Table X). In 43 cases collected by Mills, in which the sex was stated, 22 were in males and 21 in females. While most cases of spinal tumors

are reported as occurring between the ages of 20 and 50 (Woolsey), no age is free from liability and no age is peculiarly liable (Table XI). Although relatively less frequent than brain tumors, spinal tumors of all

A B

FIG. 231.—CHOLESTEATOMA REMOVED FROM THE SPINAL CORD. (Robertson.)
A, Anterior view; B, posterior view.

kinds, particularly tubercles, are found in children of all ages. Schlesinger has found that tuberculoma is one of the most common of the intramedullary growths in children under ten years of age.

TABLE X

DISTRIBUTION OF TUMORS ACCORDING TO SEX

Pathological Diagnosis	Male	Female	Not Stated	Total
Fibroblastoma:				
Fibroma	12	12	2	26
Fibro-adenoma	1	..	..	1
Fibro-endothelioma	2	1	..	3
Fibromyoma	..	1	..	1
Fibromyxoma	3	1	..	4
Fibromyxosarcoma	2	..	..	2
Fibrosarcoma	19	10	..	29
Myxoblastoma:				
Myxoma	2	1	..	3
Myxolipoma	..	1	..	1
Myxosarcoma	..	1	..	1
Chondroblastoma:				
Enchondroma	3	3	..	6
Chondrosarcoma	..	2	..	2
Osteoblastoma:				
Osteoma	3	1	..	4
Osteofibrosarcoma	1	..	..	1
Lipoblastoma:				
Lipoma	..	2	2	4
Endothelioblastoma:				
(a) Hemangio-endothelioblastoma:				
Angioma	4	..	..	4
Angiofibrosarcoma	1	..	..	1
Angiolipoma	..	2	..	2
Angiosarcoma	1	3	..	4
(b) Lymphangiendothelioblastoma:				
Lymphangioma	1	..	..	1
(c) Dural endothelioblastoma:				
Dural endothelioma	10	14	1	25
Lymphoblastoma:				
Lymphosarcoma	..	1	1	2
Myelomablastoma:				
Myeloma	3	..	..	3
Melanoblastoma:				
Melanoma	2	..	1	3
Glioblastoma:				
Glioma	8	8	1	17
Gliosarcoma	2	2	..	4

Pathological Diagnosis	Male	Female	Not Stated	Total
Neuroblastoma:				
Neurofibroma	4	2	..	6
Neurofibro-angioma	..	1	..	1
Neurofibroglioma	..	1	..	1
Neurofibrosarcoma	..	1	..	1
Epithelioblastoma:				
Adenoma	1	1	1	3
Carcinoma	2	8	..	10
Embryoblastoma:				
Teratoma	1	..	..	1
Dermoid	1	1	..	2
Inflammatory-reaction processes:				
Tubercle	5	2	1	8
Gumma	1	..	..	1
Cysts	5	3	2	10
Unclassified:				
Hydatid	9	2	..	11
Psammoma	1	12	..	13
Sarcoma	43	18	5	66
Not stated	16	17	9	42
TOTAL	169	135	26	330

Course and Duration.—The clinical course of spinal tumors, as of all tumors, depends upon the nature of the tumor and its rate of growth. For the most part, however, like tumors of the central nervous system elsewhere, they are slow in development, running a course from 6 months to 3 years, the average duration in our collection being 28.4 months. Reckoning from the onset of the first symptoms to the time of operation, the shortest course was 15 days, and the longest, 14 years. Occasionally, the irritation phenomena may be present for years before any signs of compression appear, and sometimes there are periods of remission which may lead to errors in diagnosis. On the other hand, even benign tumors may run a relatively short course, as in Schultze's case, in which death occurred four months after the first symptoms had appeared. Autopsy revealed a well circumscribed endothelioma the size of a hazelnut, between the dura and pia at the level of the seventh thoracic segment. So that whether the tumors be benign or malignant, there is the greatest lack of uniformity in the clinical course with periods of growth interrupted by periods of latency or even of temporary improvement. Tumors of the cauda are of longer duration, because they have more space in which to

TABLE XI

DISTRIBUTION ACCORDING TO AGE

Pathological Diagnosis	1–9	10–19	20–29	30–39	40–49	50–59	60–69	Not Stated	Total
Fibroblastoma:									
Fibroma	1	4	6	4	5	3	..	3	26
Fibro-adenoma	..	..	..	..	1	..	..	..	1
Fibro-endothelioma	..	..	..	..	2	..	1	..	3
Fibromyoma	..	..	..	..	1	..	..	..	1
Fibromyxoma	..	1	1	..	2	..	..	..	4
Fibromyxosarcoma	..	..	..	..	..	1	1	..	2
Fibrosarcoma	..	4	3	7	5	7	3	..	29
Myxoblastoma:									
Myxoma	..	..	1	..	..	1	..	1	3
Myxolipoma	..	..	..	..	1	..	..	..	1
Myxosarcoma	..	..	..	1	..	..	..	..	1
Chondroblastoma:									
Enchondroma	..	..	1	1	2	1	1	..	6
Chondrosarcoma	..	..	1	1	..	..	..	..	2
Osteoblastoma:									
Osteoma	..	..	..	1	1	2	..	..	4
Osteofibrosarcoma	..	..	1	..	..	..	..		1
Lipoblastoma:									
Lipoma	..	..	1	.	..	..	..	3	4
Endothelioblastoma:									
(a) Hemangio-endothelioblastoma:									
Angioma	..	..	1	1	1	1	..	..	4
Angiofibrosarcoma	..	..	..	..	..	1	..	..	1
Angiolipoma	..	..	..	..	..	2	..	..	2
Angiosarcoma	..	..	2	..	1	1	..	..	4
(b) Lymphangio-endotheliblastoma:									
Lymphangioma	..	1	..	..	..	..	..	..	1
(c) Dural endotheliblastoma:									
Dural endothelioma	..	2	5	5	6	2	1	4	25
Lymphoblastoma:									
Lymphosarcoma	..	..	..	1	..	..	..	1	2
Myelomablastoma:									
Myeloma	..	..	..	1	2	..	..	..	3
Melanoblastoma:									
Melanoma	..	..	1	1	..	..	1	..	3

Pathological Diagnosis	1–9	10–19	20–29	30–39	40–49	50–59	60–69	Not Stated	Total
Glioblastoma:									
Glioma	1	1	3	3	4	2	..	3	17
Gliosarcoma	..	..	1	..	3	..	..	..	4
Neuroblastoma:									
Neurofibroma	..	1	3	..	2	..	..	..	6
Neurofibro-angioma	..	..	..	..	1	..	..	..	1
Neurofibroglioma	..	..	..	..	1	..	..	..	1
Neurofibrosarcoma	..	..	1	..	..	..	..	..	1
Epithelioblastoma:									
Adenoma	..	..	..	1	1	..	..	1	3
Carcinoma	..	1	..	2	4	1	1	1	10
Embryoblastoma:									
Teratoma	..	..	..	1	..	..	..	..	1
Dermoid	..	1	1	..	..	..	..	..	2
Inflammatory-reaction processes:									
Tubercle	..	..	1	3	1	1	..	2	8
Gumma	..	..	..	..	1	..	..	..	1
Cysts	..	2	1	2	3	..	..	2	10
Unclassified:									
Hydatid	..	1	4	2	4	..	..	..	11
Psammoma	..	..	1	..	9	1	1	1	13
Sarcoma	2	4	15	15	11	8	5	6	66
Not stated	..	1	6	10	9	4	2	10	42
TOTAL	4	24	61	63	84	39	17	38	330

expand, but for some unknown reason, tumors in the lumbar and thoracic regions appear to grow more rapidly.

Symptomatology.—Spinal tumors, whether extramedullary or intramedullary, whether they arise in the spinal cord itself, in the meninges or in the vertebrae, make themselves manifest sooner or later through involvement of the spinal nerve-roots and their respective segments in the spinal cord, and sometimes of the vertebral column. The damage which they inflict upon the nervous tissue takes the form first of irritation, then of compression, encroachment or destruction, depending partly on the origin and location of the lesion and partly on its character and rate of development.

There are *three established cycles* in the life history of the spinal tumor. The *first or root cycle* is usually the longest, and the symptoms, generally unilateral in the early stages, are caused first by irritation and

later by compression of the roots involved. Hence, we find paresthesias, pain, hyperesthesias, hypesthesias and anesthesias in the areas innervated by the affected posterior roots; and tremors, muscular spasms and spasticities followed by muscular atrophy and paresis in the distribution of the involved anterior roots. The latter group of symptoms is by no means constant, as tumors involving the anterior surface are relatively infrequent. It should be remembered, too, that the clinical course is not always marked by a steady progressive loss of function, but may be interrupted by waves of latency or delusive calms. The *second cycle* is that of the Brown-Séquard syndrome, paralysis of motion and deep sensation on the side corresponding to the tumor, and on the opposite side, impairment, especially of pain and temperature sensation, below the seat of the lesion. This cycle is almost constant, unless the tumor has arisen within the cord itself, since, on account of the lateral location of most tumors, one side of the cord must necessarily be compressed before the lesion becomes transverse. Oppenheim has known only one case of extramedullary tumor in which the third stage was not preceded by the Brown-Séquard syndrome. Sooner or later, however, increasing compression causes total interruption of conduction and the Brown-Séquard syndrome is overshadowed or replaced by complete bilateral motor and sensory paralysis of all parts, the innervation of which is below the seat of the lesion. This *third cycle* is characterized by weakness and later paralysis of the bladder and rectum, first exaggeration and finally abolition of all reflexes, whose arcs are involved, and by various vasomotor and trophic disturbances.

It must, however, be borne in mind that there is no sharp dividing line between these three cycles and that, because of variation in the location and origin of the tumor, the clinical picture is by no means characteristic or constant. It may happen, even when the tumor is of meningeal origin, that the root symptoms are absent. Not only is pain usually lacking in intramedullary tumors, but the evolution of the complete interruption of conduction is much more rapid and often is not preceded by the unilateral Brown-Séquard syndrome. On the other hand, in cases of intramedullary tumors, occasionally the root symptoms may be a prominent feature, probably because the tumor is situated very near the point of entrance of the posterior roots. Moreover, we sometimes find that the neuralgic pains are present in the paralyzed parts even if the compression is almost transverse, giving the picture of paraplegia dolorosa of Cruveilhier. The phenomenon has been explained by Schultze on the ground that the conductivity of those fibers transmitting pain sensation to the brain has not been entirely destroyed, while, on the other hand, in some cases it is destroyed so early that no pain whatever is experienced. Absence of pain, however, in the early stages, may also be attributed to the non-

involvement of the sensory roots due to the location of the tumor on the anterior or intraradicular aspects of the cord.

In spite of the many variations in the symptoms of the three cycles, a careful study of their symptomatic evolution is most important, and makes it possible to differentiate tumors from other affections of the spinal cord with many of the same general characteristics. The roentgenogram is of little use for this purpose, except where we suspect a vertebral tumor or wish to determine whether a growth of meningeal origin has invaded the vertebrae. Analysis of the cerebrospinal fluid is of assistance only in rare instances, as there is nothing significant about the amount of albumin, and the citron-yellow color is present in many of the infectious diseases of the spinal canal (*vide* chapter on The Cerebrospinal Fluid and Its Relation to Spinal Disease). Hence, we must depend almost exclusively upon a careful interpretation of the clinical signs to determine whether we are dealing with a tumor or some other lesion of the spinal canal. It is usually difficult and often impossible to determine before operation the exact character of the tumor in spite of a careful review of the clinical data at hand.

In contemplating operation on spinal tumors, the determination of their precise location both as to the level and the aspect of the cord involved must be seriously studied. With our present knowledge of the anatomy and physiology of this particular part of the nervous system, and a careful interpretation of the clinical data available, it is often possible to determine the segment involved, whether the tumor is anterior or posterior to the cord and whether it takes its origin from the vertebrae, the meninges or the cord. Each variety of spinal tumor, the extramedullary, the intramedullary and the vertebral, has a more or less definite symptom-complex, but it may in many respects so closely resemble that of the others, that the most careful analysis is required to differentiate one from the other. However, each of these three varieties of spinal tumors may be said to conform to type in certain instances. The investigations of Head and others have placed at our disposal much accurate information concerning the distribution and function of the spinal nerve-roots, and notably through the work of Déjerine, Petrén, Schultze, and Rothmann we have a fairly definite knowledge of the functions and course of the various tracts of the spinal cord. A careful correlation of these facts with the results of clinical examinations, operative findings, autopsy reports and microscopical examinations has made it possible to evolve a definite symptom-complex.

Extramedullary Tumors.—Tumors of the meninges seldom invade or destroy the cord itself, save for a slight marginal demyelinization, but rather make themselves manifest through irritation and compression of the nerve-roots and later of the cord. Usually slow and insidious in evolu-

tion, they occur principally in persons between forty and fifty, though occasionally in younger people.

The root symptoms are the first to appear, often existing for a comparatively long period (two to eight years) and extending over several segments before there are any signs of pressure upon the cord. This is due in part to their slow growth and in part to their rapid conformity to the contour of the space in which they develop, for although they may be round or oval in the beginning, eventually they become cylindrical. In these cases, vertebral symptoms are either entirely lacking, especially when the lesion is intradural, or appear very late. The so-called root symptoms are the result first of irritation, and later of compression of the roots themselves, their points of origin from the cord and their respective segments. Since the majority of meningeal tumors are situated on the lateral or posterolateral aspect of the cord, and only rarely on the anterior surface, the anterior roots are seldom involved in the early stages. Hence, the conspicuous absence of marked motor phenomena until the disease has progressed far enough to affect the motor columns of the cord. For the same reason, the nerve-roots and cord are usually affected on but one side at first, and this corresponds to the site of the tumor. These data are invaluable for the purpose of localization.

Before actual pain is experienced, and this is the cardinal symptom of the root period, there is paresthesia, such as the sensations of tingling, itching, numbness and formication, in the region supplied by the roots already involved. I find in most of my patients that this feeling of discomfort and numbness is localized to one spot in the beginning, but that it gradually involves a whole extremity and sometimes both upper and lower extremities on the affected side; such was the case in one of my patients with a tumor of the cervical region, the initial symptom being tingling and numbness, first in the left arm, then in the leg and foot (*vide* p. 600).

Because of its subjective character the diagnostic value of pain is limited. It is felt in regions supplied by certain nerves in the neck, arms, hands, abdomen, legs or feet, according to the seat of the lesion. The pain is usually trivial at first, limited to a definite area, and unilateral in character. Gradually becoming more severe, and paroxysmal in character, it manifests itself in pricking, burning and cutting sensations which are at times mistaken for periodic gastralgia or gallstone colic. It may disappear for a time, to reappear in the form of a heavy, dull pain with occasional exacerbations. Pain is intensified by active or passive motion, sudden changes in position and extreme muscular tension, such as sneezing or coughing, and so marked is the hyperesthesia over the painful area that it is almost impossible for the patient to stand the slightest rubbing or brushing over this region. This neuralgic period may extend over several months or even several years, before other symptoms appear,

as in one of Oppenheim's cases where intercostal neuralgia was the only symptom for two and a half years. This fact, alone, is responsible for many of the erroneous diagnoses made in the early stages of the disease. According to the seat of the pain, a diagnosis of sciatica, angina pectoris, or intercostal neuralgia is often made. There are, however, certain peculiarities which should be borne in mind. The pain accompanying spinal tumors is not ordinarily increased by pressure on the nerve or attended by tender spots, and there is no other disease in which the pain is so definitely localized and so persistent. The distribution and localization are dependent, of course, upon the site of the tumor and upon the segments and roots involved. For example, when the tumor is in the upper cervical region, the pain will usually be localized in the neck and shoulder; when it is a little lower, we find the pain in the hand and arm. When the tumor is in the mid-thoracic region, the pain is principally in the chest and pectoral region, while a tumor in the lowest thoracic segment will cause pain in the abdomen and groins and lesions of the cauda will cause pain along the sciatic nerve. Occasionally, if the tumor be directly posterior to the cord, the pains will be bilateral from the first and of great severity, encircling the entire abdomen or thorax, or embracing both shoulders. At any rate, after it has persisted for some time, it gradually becomes bilateral, though often only after the symptoms of compression have appeared. This is an important sign, as it indicates that the tumor is assuming large dimensions and will soon inflict irreparable damage on the cord. As the tumor increases in size, often not only the posterior roots are involved, but the sensory tracts as well, causing painful sensations in distant parts. Pain, however, is of diagnostic value only when it is limited to a definite area.

Whether unilateral or bilateral, localized or diffuse, pain is by no means invariable or constant. Spinal tumors with no pain throughout their course are not so unusual as supposed. Schultze has seen five cases of extramedullary tumors without pain, and similar cases have been reported by Oppenheim, Bailey, Clarke, and Sibelius. In his recent review of extramedullary tumors, Serko found that in half of these the neuralgic period was lacking and, of the atypical cases, 16.6 per cent of the intradural tumors and 29.5 per cent of the extradural tumors ran a completely painless course. In the remainder of the atypical cases, pains due to compression of the long sensory tracts in the cord characterized the intradural lesions, and pains in the back, the extradural. It is interesting to note in this connection that a painless course is almost twice as common with tumors arising extradurally, as with those taking their origin within the dura. Bailey cites several cases of spinal tumors in which pain was entirely lacking or irregular in its manifestations, the periods between attacks often being very protracted. Indeed, when compression has caused paralysis of the tracts carrying the sensory stimuli cerebralward, pain,

as Schultze points out, can easily be entirely lacking, or can be very trivial and disappear early in the course of the disease. Likewise, it is conceivable that a small tumor on the anterior or intraradicular aspect of the cord might cause no disturbance of the posterior roots and their respective segments. Thus, in view of the fact that pain in spinal tumors may be entirely lacking, so trivial or intermittent that it mimics the pain accompanying purely degenerative processes, or projected so far from the site of the lesion that its relation thereto is not suspected, we should not be led astray by such deviations from type; if the other symptoms be sufficiently typical, we should never await the development of pain before making a diagnosis.

Attention may be called again to the area of hyperesthesia exactly over the region of spontaneous pain, especially early in the course of the tumor, as a sign of great diagnostic value. This zone, which may show both thermic and tactile variations, is the result of irritation of the roots.

While symptoms of sensory root irritation appear early in the development of the disease and are more or less constant, irritation of the motor roots is more rare, and evidence of it appears, if at all, so late in the course of the disease as to be relatively of less importance. When, however, the tumor happens to be in close proximity to the anterior roots, especially in the region of the cervical or lumbar enlargements, motor disturbances are a natural sequence. The incipient motor phenomena consist in tremors and in spasmodic contractions, either tonic or clonic in type, and limited to certain muscles or groups of muscles. The spontaneous spasmodic twitchings may be extreme and distressing, occasionally necessitating the binding of a limb to the bed, as in the following case, which was under the observation of Dr. Charles K. Mills at the University Hospital:

The patient, a young woman (File No. 11647), in February, 1912, began to have dull, aching pains in the back, in the region of the fourth and fifth thoracic vertebrae. Two months later, the lower limbs became weak and unsteady, and then completely paralyzed, paralysis of the bladder occurring at about the same time. The most distressing feature, however, was the intermittent spasmodic contractions of the legs, which were frequent, especially at night; at times they were severe enough to raise the legs to a considerable height, and at other times the jerkings were confined entirely to the feet. There was profuse sweating at night. Thermal and pain sensations were impaired up to the level of the fourth rib, and there was an increasing sense of constriction about the body at the highest level of impairment of sensation. At times there was also disturbance of muscle sense in giving the impression that the lower extremities were raised when flat and *vice versa*. The lesion was thought to be in the spinal canal at the level of the fourth and fifth thoracic vertebrae.

These contractions most frequently concern the arms or legs, but occasionally they take the form of torticollis or retraction of the head. In ex-

ceptional instances general convulsions with unconsciousness have been said to accompany spinal tumors and fibrillary twitching is rare. The contractions are often lacking, and when present, are soon overshadowed by degenerative paralysis of the respective muscles. In the later stages of the disease there are frequently painful contractures of the limbs upon the body.

Just as irritation of the motor roots is infrequent and late in appearance, so signs of compression of these roots occur only after the lesion has become very extensive, manifesting themselves in atrophy and disturbed electric excitability of the muscles involved. Nutritional disturbances are caused only by extensive lesions, and therefore call for immediate intervention if the growth can be located. Complete atrophy of a given muscle usually implies the compression of at least three adjacent roots, as most muscles receive their innervation from not less than this number. Occasionally in this period we find edema and herpes, although these are more frequently manifestations of a later stage of the disease.

FIG. 232.—FIBROMA AT THE LEVEL OF THE FIRST THORACIC SEGMENT ON THE ANTERIOR ASPECT OF THE CORD.

The expansion of the tumor almost invariably causes compression of the posterior roots. The neuralgic area then becomes anesthetic, and sometimes this area is extended in both directions and sometimes only above or below the original area of pain. When the posterior roots are involved very near the posterior segments of the cord, the anesthesia soon becomes profound, though it may be variable in distribution for a time. "One leg or one arm may be partially involved, or both lower or both upper extremities, or certain portions of any one of the limbs" (Mills). There may be anesthesia dolorosa. The observation of Sherrington that the conduction of at least three adjacent posterior roots must be destroyed before there is complete anesthesia in the domain of a single root, is one which is borne out by my own experience, as well as by that of others. This fact must be given careful consideration, for a definite area of anesthesia, even though small, much smaller than the area of pain and hyperesthesia, is indicative of an extensive lesion. At times the area of anesthesia encircles the body. In one of my cases, the patient had a band of anesthesia extending from just below the nipple line to the epigastrium. The lesion, a fibroma, was found to be situated on the anterior aspect of the spinal cord at the level of the first thoracic segment (Fig. 232).

A case illustrating the motor and sensory disturbances caused by a tumor on the anterior aspect of the cord at the level of the first thoracic segment.

The patient, *aet.* 56, a year before admission suffered from a severe attack of neuritis in the right hand, the pain being so intense as to necessitate the arm being carried in a sling. Accompanying this was an area of deep-seated pain along the left side of the spine between the scapulae. Two months later the patient experienced severe pain in the left foot, which lasted about three weeks; two months after this attack, there developed a sensation of constriction and numbness just above the waist which extended around the body and this was attended by a bloated feeling in the abdomen. In walking, the left leg at first seemed to lag a little, and while there was a decided weakness in both legs, it was much more marked in the left. These symptoms were followed in succession by numbness and loss of sensation below the waist, by loss of control over the bladder and rectum, by painful contractions of the lower limbs and by darting pains in the legs which extended up the spine to the sensitive point between the shoulders on a level with the third thoracic vertebra. There was a constant burning sensation in the limbs, and the patient had a bed sore of about three weeks' duration. Four months prior to admission a roentgenogram of the lower cervical and upper thoracic region showed nothing abnormal.

Physical Examination.—Sensory Disturbances. Thorax and abdomen: The upper level of tactile anesthesia was limited anteriorly on the left by the upper margin of the fourth rib; on the right it was a trifle lower. Demarcation between the anesthetic and normal areas was sharp, although immediately above the line of demarcation sensation was not so marked as normal. Posteriorly the sensory disturbance was limited by a line between the third and fourth thoracic vertebrae. Sensation for pain corresponded very closely to that for tactile stimuli, though there was a tendency for the analgesia to be slightly higher than the tactile anesthesia. The limiting line for heat and cold stimuli was practically that for tactile sensation. Upper extremities: Tactile, pain and temperature stimuli were normally perceived on each side, and no distinction recorded between the ulnar and radial sides on either limb. Pain stimuli were possibly more keenly felt in the face than in the upper extremities. Lower extremities: Tactile, pain and temperature stimuli showed complete loss of these forms of sensation on each side (Fig. 233). *Motor Disturbances.* Upper extremities: There was no motor abnormality present. Lower extremities: Thighs were flexed on the trunk, and the legs flexed at a right angle with the thighs, extension by passive movement being impossible. The lower limbs were extremely rigid. *Reflex Disturbances.* Upper extremities: There was no disturbance of reflex action in the upper limbs. Lower extremities: Patellar tendon reflexes were not obtained because of the spasticity. Persistent ankle clonus was present on each side when the rigidity was sufficiently relaxed to make the test possible. Involuntary jerking of the lower limbs was very pronounced. There was absolute loss of control of the bladder and rectum. *Trophic Disturbances.* To the right of the median line over the right buttock there was an area of superficial ulceration which began as a pin scratch and later extended to about five centimeters in diameter.

Constriction or girdle sensations are among the most distressing symptoms of spinal tumors. When the tumor is located in the upper cervical region, there is frequently a choking sensation about the neck, while a tumor in the lower cervical or thoracic region is often accompanied by a

girdle sensation about the chest or abdomen. This, however, cannot be used as an absolute test as to the location of the lesion, inasmuch as it is often lacking, or it may take a most unexpected form. Mills cites a case in which a myxoma at the level of the sixth and seventh cervical vertebrae caused a constriction sensation about the legs and abdomen, and also one in which a glioma of the filum terminale caused a sense of constriction about the chest.

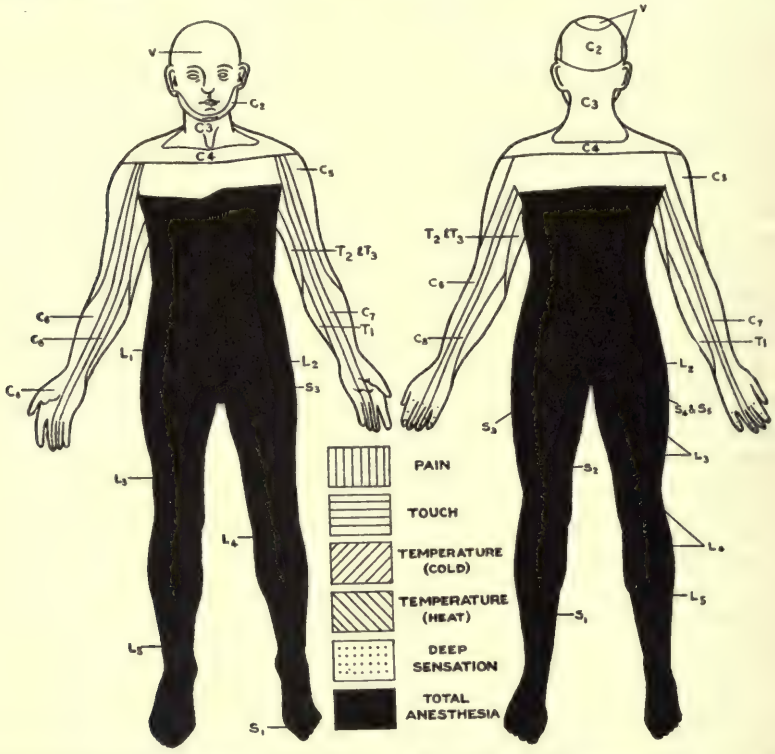

FIG. 233.—CHART OF SENSORY DISTURBANCES IN CASE OF TUMOR ON ANTERIOR ASPECT OF CORD AT LEVEL OF THE FIRST THORACIC SEGMENT.

Though the intervening pia is a very thin membrane, extramedullary tumors rarely invade the cord itself, unless they originate in the pia. Notwithstanding this fact, merely by pressure the functions of the cord may be disturbed and its conductivity interrupted. The development of compression symptoms is usually very slow and often compression may have persisted for a long time without irreparable damage to the cord; but sooner or later, if the pressure be not removed, death will ensue, with the intervening years full of unbearable suffering. There is the greatest variation in the rate of growth of these tumors; some soft neoplasms, developing rapidly, cause a complete transverse lesion at an early stage through edema or hemorrhage into the cord; again, on account of the

lateral origin of many of the meningeal tumors, often only one side of the cord may be compressed. Under these circumstances, when the tumor is above the lumbar region, we may see the Brown-Séquard syndrome. This is characterized first by weakness of the extremities, later by most distressing spastic contractures of the thigh and leg, foot clonus and exaggeration of the tendon reflexes, and finally by paralysis of motion and loss of deep sensations, on the side corresponding to the seat of the tumor. There is also a more or less transitory hyperesthesia to pain, touch and temperature over the skin on this side, and later a homolateral zone of anesthesia corresponding to the area supplied by the posterior roots involved, and above this there may be an area of hyperesthesia. There is often an elevation of temperature, caused by vasomotor paralysis, in the parts paralyzed and in the hyperesthetic zone just mentioned. On the contralateral side, voluntary movements are normal, but there is impairment of pain and temperature sensation with occasional disturbance of tactile sensation, beginning in the feet as hyperesthesia and gradually rising until it reaches the level of the tumor, and almost always there is exaggeration of the patellar and Achilles reflexes. On the contralateral side there is also a narrow band of hyperesthesia at the level of the tumor, and directly below this we occasionally find a belt of complete anesthesia. Deep sensations are unaffected on this side. This peculiar symptom-complex may be explained by the course of the tracts within the spinal cord. While the tumor still affects only one side of the cord, the motor disturbances are homolateral because the motor tracts, after they cross at the anterior pyramids of the medulla oblongata (Fig. 234), run uncrossed throughout their course in the cord. On the other hand, the sensory fibers for pain and temperature sensations cross in the cord.

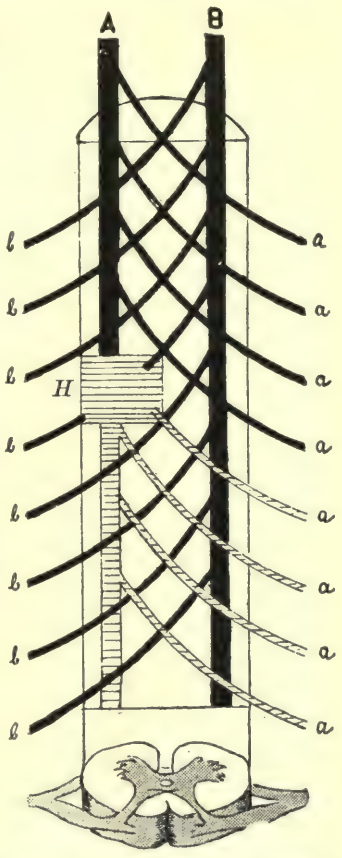

FIG. 234.—DIAGRAMMATIC REPRESENTATION OF BROWN-SÉQUARD SYNDROME. (Jacobsohn.)

A and B, Sensory conduction system of one-half of cord; H, lesion.

These disturbances will vary somewhat according to the extent of the lesion and the portion of the cord involved. A slight degree of ataxia, caused by compression of those fibers entering the posterior columns be-

low the lesion, is observed in all muscles receiving their innervation from this source. This is frequently masked by the paralysis, and therefore is not so conspicuous as we would expect from the important part the posterior columns play in coördination. Great distress is sometimes caused by the board-like tension of the abdominal muscles. The irritative symptoms, pain, hyperesthesia, hypesthesia and spasms, become more and more exaggerated, though later, as compression arrests the cord function, spasticity gives way to flaccidity.

Occasionally the Brown-Séquard symptom-complex is entirely lacking, as in a case reported by Nonne, in which a fibro-endothelioma, compressing the seventh and eighth thoracic segments, was removed at operation. The patient, a man forty-eight years of age, had experienced severe pain in the buttocks and in the upper and lower extremities three years before the operation. The gait had been slow and hesitating for a year, the right leg weak and somewhat ataxic, and the bladder wall had become paralyzed. The upper extremities were then intact, but finally pain appeared in the neck and right arm. Similar cases have been reported by Schultze, Auerbach and Brodnitz. Another exception to the usual sequence of events is Palmen's case, in which the Brown-Séquard syndrome was present, although microscopical examination revealed a fibrosarcoma compressing both posterior columns symmetrically. We cannot, therefore, attach too much importance either to the presence or to the absence of the Brown-Séquard syndrome, no more importance at least than is attached to the presence or absence of pain.

The absence of the Brown-Séquard syndrome in cases of extramedullary lesions is a little difficult to explain, though it is conceivable that a unilateral compression may very rapidly involve the other side through distortion of tissue, or the entire cord may be seriously compressed at once. At any rate, the whole cord eventually becomes involved; exaggeration of reflexes becomes bilateral and the hemiparesis passes into paraparesis or rather paraplegia, though a part of the Brown-Séquard syndrome may persist even after the lesion has become transverse in most respects, as in one of Oppenheim's cases in which the homolateral spastic paralysis was connected with hypotony of the quadriceps and weakening of the patellar reflexes; the anesthesia in the lower extremities was bilateral, while thermal anesthesia was found only on the side opposite the tumor. Beginning in the legs, and gradually extending upward, with the level of sensory disturbance remaining just behind that of the motor, the motor and sensory paralyses become profound. We often find atrophic paralysis of single groups of muscles; for example, if the tumor be situated in the lower cervical region there may be weakness of the muscles of the hand, as in one of my cases (*vide* p. 600). The tendon reflexes are at first tremendously exaggerated, so that the merest touch will cause severe muscular contractions, but finally, as interruption in conduction be-

comes complete, they may be entirely abolished. Patients suffer excruciatingly from paralysis of the abdominal muscles, especially from eructations and vomiting and a constant feeling of distention. The bladder becomes paralyzed, function of the rectum and genital organs is disturbed to a greater or less degree, and visceral anesthesia becomes complete below the seat of the lesion. These latter phenomena are a constant phase of the paraplegic period.

Among the trophic changes in these tumors, we find glossy skin, edema, ulcers, decubitus and finally cystitis and pyelitis. Vasomotor disturbances may also be present in the form (1) of pallor, cold skin or hyperemia, (2) of Raynaud's phenomena or acroasphyxia, (3) of erythromelalgia and (4) of a transitory edema. These vasomotor phenomena are a later rather than an earlier manifestation of cord lesions and are by no means constant. Even with his rich clinical material, Schlesinger has seen but one case of erythromelalgia (in this instance with severe pain, swelling and hyperemia on the dorsum of the foot), and I can recall none in my own clinic. Among the surface phenomena should be included hyperidrosis or anidrosis. When the tumor is situated in the upper cervical region very near the medulla, there are superimposed bulbar symptoms, such as cardiac palpitation, dyspnea, paralysis of deglutition, dysarthria and aphonia. Very rarely is there evidence of intracranial involvement with amblyopia, diplopia, deafness, contracted pupils, paralysis of the motor fifth and abducens, and occasionally optic neuritis, as in a case reported by Nonne. Since the origin of the

Fig. 235.—Endothelioma of the Posterior Surface of the Dura, Extending from the Sacral to the Cervical Region. (Spiller.)

spinal root of the trigeminal nerve extends down to and includes the third cervical segment, one would expect to see involvement of that nerve in tumors in the uppermost part of the cord. But we have not found a case reported in literature in which the trigeminal region was affected when the tumor was limited to the cord itself. The skin reflexes, like the tendon reflexes, are exaggerated in the beginning, and disappear as the lesion becomes completely transverse. The Babinski reflex is usually present and sometimes both the Bechterew and the Mendel reflexes. Finally, when the lesion has become entirely transverse, there is complete paralysis, both motor and sensory, below the seat of the lesion.

At times, particularly in extradural tumors, the vertebral column becomes involved. Among the characteristic phenomena of the early stage, there are often pain in the back, slight stiffness and limitation of motion in the affected region, and sometimes localizing pains and tenderness to pressure on the spinous processes. The body is frequently held in a stiff position, and scoliosis develops from the tendency to maintain the position causing least pain. Out of 85 cases, Krause found that tenderness was present in 31 cases, absent in 15 and not mentioned in the others. When present, these vertebral symptoms are a great aid in topographical diagnosis, but always in connection with other localizing signs.

The evolution of the history of extramedullary tumors is slow, but progressive. Patients passing through the three cycles above described, the root period, the stage of the Brown-Séquard syndrome and finally the period of the transverse lesion, have in the past, before surgery was resorted to, been known to have been bedridden for fifteen to twenty years, until death resulted from decubitus, cystitis and pyonephrosis. This group comprises by far the largest number of operable cases, according to Potel and Veaudeau, 77 per cent. Sarcoma and fibrosarcoma are the most common varieties, the order of frequency of the other pathological types given by Potel and Veaudeau being as follows:

TABLE XII

Sarcoma in its various forms	80	per cent
Endothelioma	6	" "
Psammoma	3	" "
Dermoid cyst	2	" "
Angioma	1	" "
Lymphangioma	1	" "
Hydatid cyst	3	" "
Carcinoma	4	" "

Varying in size the tumors are usually elongated (Fig. 235), especially those of extradural origin, and measure often two to five centimeters in length. The majority arise from the dura mater and are situated on its posterolateral aspect. We have compiled the following tables of extramedullary tumors of intradural (Table XIII) and extradural (Table

TABLE XIII

EXTRAMEDULLARY TUMORS (INTRADURAL)

Pathological Diagnosis	Cervical	Thoracic	Lumbosacral	Total
Fibroblastoma:				
Fibroma	2	4	1	7
Fibro-adenoma	..	1	..	1
Fibro-endothelioma	2	1	..	3
Fibromyxoma	..	1	..	1
Fibromyxosarcoma	..	1	..	1
Fibrosarcoma	4	4	1	9
Myxoblastoma:				
Myxoma	1	..	..	1
Endothelioblastoma:				
(a) Hemangio-endothelioblastoma:				
Angioma	..	1	..	1
Angiosarcoma	1	2	..	3
(b) Dural endothelioblastoma:				
Endothelioma	8	8	..	16
Lymphoblastoma:				
Lymphosarcoma	..	1	..	1
Glioblastoma:				
Glioma	1	5	..	6
Neuroblastoma:				
Neurofibroma	3	2	..	5
Neurofibro-angioma	..	1	..	1
Neurofibroglioma	..	1	..	1
Inflammatory-reaction processes:				
Tubercle	..	1	..	1
Gumma	1	..	..	1
Cyst	..	5	..	5
Unclassified:				
Psammoma	..	13	..	13
Sarcoma	2	8	..	10
Not stated	3	7	..	10
TOTAL	28	67	2	97

XIV) origin, showing the relative frequency of the different varieties at various levels.

Extradural and Intradural Tumors.—While we can now differentiate with a fair degree of certainty between the extramedullary and intramedullary growth before operation, it is difficult and often impossible

TABLE XIV

EXTRAMEDULLARY TUMORS (EXTRADURAL)

Pathological Diagnosis	Cervical	Thoracic	Lumbosacral	Not Stated	Total
Fibroblastoma:					
Fibroma	2	3	..	1	6
Fibromyxoma	..	1	..	..	1
Fibrosarcoma	4	2	1	..	7
Myxoblastoma:					
Myxoma	..	1	..	..	1
Endothelioblastoma:					
(a) Hemangio-endothelioblastoma:					
Angioma	..	2	..	..	2
Angiolipoma	..	2	..	..	2
Lymphoblastoma:					
Lymphosarcoma	..	1	..	..	1
Myeloblastoma:					
Myeloma	1	..	..	..	1
Epithelioblastoma:					
Adenoma	..	1	..	..	1
Embryoblastoma:					
Teratoma	..	..	1	..	1
Dermoid	..	1	1	..	2
Inflammatory-reaction processes:					
Tubercle	..	2	1	..	3
Cyst	..	1	..	..	1
Unclassified:					
Hydatid	..	5	4	..	9
Sarcoma	2	11	..	..	13
Not stated	..	3	..	1	4
TOTAL	9	36	8	2	55

to distinguish between the two varieties of extramedullary tumors, the extradural and the intradural. Extradural tumors arise from the outer surface of the dura or from the dural sheath of the roots and grow from above downward. The period elapsing between the onset of the root disturbances, especially the neuralgic pains, and the cord symptoms is, however, much longer with extradural tumors because the latter have a tendency to grow longitudinally, involving a number of nerve-roots, before seriously compressing the cord. In one of Schultze's cases in which an

extradural fibroma was found, the cord pressure symptoms did not appear until eight years after the root pains. The vertebrae are more frequently and more extensively involved when the growth originates epidurally, and the root symptoms are more likely to be bilateral from the beginning. These are the principal points in the differential diagnosis which I have gleaned from my own experience and from that of others.

Intramedullary Tumors.—Although far from common, tumors within the cord are not so rare as has been supposed. Schlesinger found that out of 302 spinal tumors, 125 were situated in the cord substance. I have collected 36 cases of intramedullary tumors in which operations have been performed—about 10.9 per cent of the total number. As to age, they are apt to develop between 25 and 45 years, though in this series there were 4 in patients under 25, one as young as 13, and another in a man of 63 years. Out of 25 cases in which the sex was stated, 14 developed in males and 11 in females. The course of these tumors, like that of tumors of meningeal origin, varies according to the site and character, but naturally medullary growths run a more rapid course, and the average expectation of life is only 2.29 years.

Fig. 236.—Intramedullary Angioma Removed from the First Thoracic Segment. (Schultze.)

The sequence of symptoms in intramedullary tumors is often the reverse of that in extramedullary growths, the irritation phenomena appearing only after the cord symptoms have become marked. The period of pure root disorders, especially the neuralgic pains, may be entirely lacking with the intramedullary tumor, and the progression to severe cord symptoms is much more rapid, but it should be remembered that, even in extramedullary tumors, pain may be absent. When the intramedullary growth originates near the entrance of the posterior roots, radiating pains may be encountered, while the sensory pathways upward are still intact. Schultze reports a case in which the pain was so severe that several posterior roots were resected for its relief, and at the operation an intramedullary angioma (Fig. 236) was extirpated from the first thoracic segment. The patient, a young man, 29 years of age, had suffered for several months from sharp pain in the left lower extremity and also in the back between the shoulder blades, which gradually extended girdle fashion about the thorax. There were transient pain in the neck, a typical Brown-Séquard syndrome with spasticity and later weak-

ness in the left arm and leg, and anesthesia for pain and temperature sensations on the right side. The history suggested a pachymeningitis hypertrophica, while the pain indicated an extramedullary growth. The operation, however, revealed an intramedullary angioma. Six months after the removal of the tumor the pain had not returned and the patient was able to walk without a cane, although there was still some weakness.

Thus we see that both the pain and the Brown-Séquard syndrome may be present even when the tumor is intramedullary. Indeed, the spinal canal is so small that tumors, whatever their origin, are bound sooner or later to involve the meninges, cord and roots, either directly or indirectly, and therefore the clinical signs may not be sufficiently characteristic to enable us correctly to forecast before operation whether the growth is intramedullary or extramedullary. This, however, may be said: that a rapid development of the symptoms is indicative of an intramedullary growth. If the symptoms seem to be the result of compression alone, the growth has probably developed in the meninges. The Brown-Séquard syndrome may be present with both, though it is frequently lacking when the tumor is intramedullary. If, on the other hand, symptoms which are the result of destruction of cord tissue prevail, we can be reasonably sure that we are dealing with an intramedullary tumor. Also, with the latter, there are no signs of involvement of the vertebral column, such as stiffness in the spine and increase of pain on movement of the spinal column. Whenever pain is present in the intramedullary variety, it is likely to be diffuse and of varying intensity. If the posterior columns be affected, anesthesia is often present. The motor disturbances in the form of progressive paraplegia are pronounced in tumors of the cord *per se*. The paraplegia is extremely rapid in development, and sometimes is accompanied by the Brown-Séquard syndrome, should the tumor be confined to one-half of the cord. The sphincters are affected earlier in the course of the disease, and trophic disturbances and ulcers are more constant.

Pure intramedullary tumors are usually limited to the cord itself and seldom invade either the meninges or the spinal column. Even when malignant, these growths almost invariably extend upward and downward rather than in a horizontal plane. Thus, at first sight the dura may appear normal to the naked eye, though at times the augmentation in volume in the cord is visible even through the dura. Absence of pulsation is a further guide to the seat of the lesion. Many intramedullary growths are fairly well circumscribed, a few even encapsulated, when an attempt at removal by operation may be made. According to Gowers, "these tumors in some cases blend with the substance of the cord, but in other instances they are bound by an area of softening which often isolates even invading growths." It is, as Elsberg states, difficult to estimate as to the frequency of encapsulated intramedullary tumors. A considerable number, however, have been recorded in literature, and a small number

have already been removed. The most frequent location for these, as for spinal tumors in general, is the thoracic region. In the 24 cases collected by Potel and Veaudeau the location was as follows:

TABLE XV

Thoracic	12 cases
Cervical	8 "
Cervicothoracic	2 "
Thoracicolumbar	1 case
Conus	1 "

The histological character of tumors situated within the cord is not so varied as in the extramedullary tumors. Glioma is the most common,

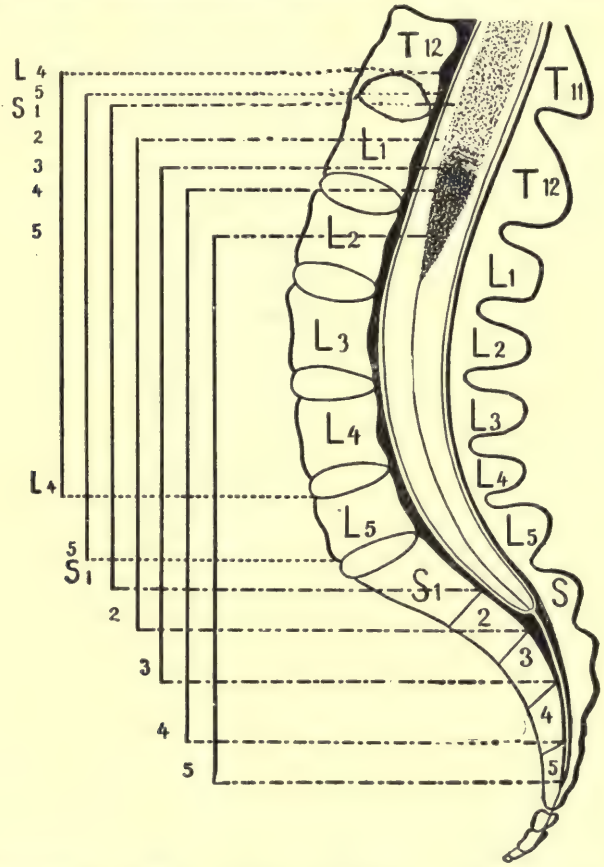

FIG. 237.—DIAGRAMMATIC DRAWING SHOWING RELATION OF ROOTS TO CORD-SEGMENTS IN CAUDAL REGION. (Jacobsohn.)

usually in the form of a single tumor, involving a large portion of the cross section of the cord and destroying both gray and white matter. Among the other pathological types are: gliosarcoma, endothelioma, sar-

coma, tuberculoma, lipoma, myeloma, gumma, fibroma, neurofibroma and neurofibrosarcoma. The last four varieties are very rare and usually well defined. The occasional tubercle may be single or multiple, is frequently associated with some other lesion of the central nervous system, and always causes great destruction of cord tissue and displacement of the different cord elements. Of 36 intramedullary tumors exposed at operation, the following table shows the relative frequency of the different types at various levels:

TABLE XVI

INTRAMEDULLARY TUMORS

Pathological Diagnosis	Cervical	Thoracic	Lumbosacral	Not Stated	Total
Lipoblastoma:					
Lipoma	2	..	..	..	2
Endothelioblastoma:					
(a) Hemangio-endothelioblastoma: Angioma	..	1	..	..	1
Melanoblastoma:					
Melanoma	1	..	..	..	1
Glioblastoma:					
Glioma	4	4	..	1	9
Gliosarcoma	1	1	..	1	3
Neuroblastoma:					
Neurofibroma	..	1	..	..	1
Neurofibrosarcoma	..	1	..	..	1
Inflammatory-reaction processes:					
Tubercle	1	2	..	..	3
Cyst	3	..	..	..	3
Unclassified:					
Not stated	3	7	1	1	12
TOTAL	15	17	1	3	36

TUMORS OF THE CONUS MEDULLARIS AND CAUDA EQUINA.—Tumors of the lower part of the cord and the cauda may be treated as a distinct group since they present a fairly definite symptom-complex which, however, varies somewhat according to the location and extent of the lesion. The lumbosacral cord extends downward to about the level of the upper surface of the body of the second lumbar vertebra; the lowest portion contains the segments for the last three sacral and the coccygeal nerves and comprises what is known as the conus medullaris. The portion just

above, containing segments of the fourth and fifth lumbar and the first and second sacral roots, is known as the epiconus medullaris. The cauda equina is made up of all the nerves springing from the lumbosacral cord

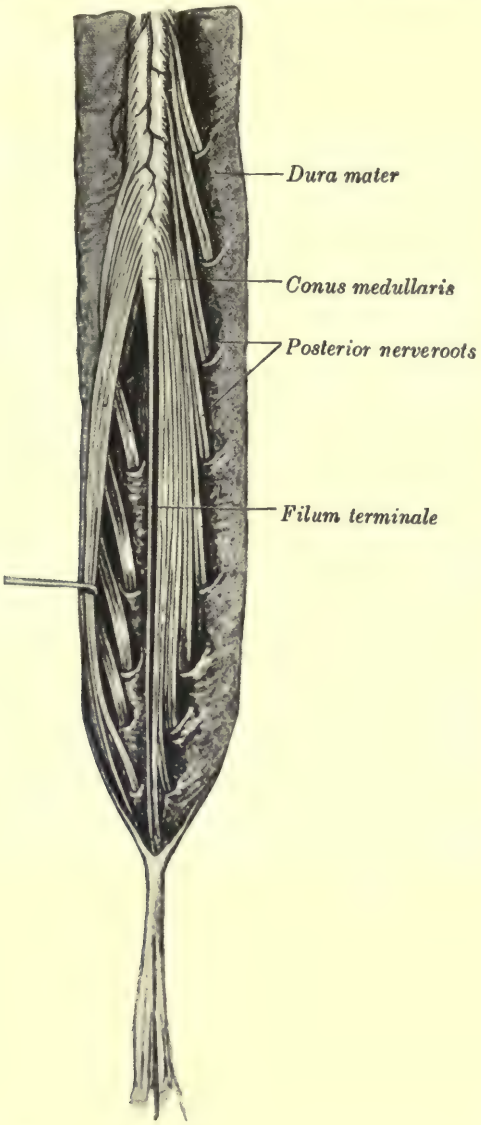

FIG. 238.—DRAWING OF THE CONUS AND CAUDA. (Gray.)

(Fig. 237). These roots traverse the spinal canal for some distance before making their exit through the intervertebral foramina, a fact to be borne in mind in localization (Fig. 238). For example, the fourth

sacral roots traverse the canal for 20 cm. before making their exit through the fourth sacral foramina. The precise location of a growth is, therefore, difficult and at times impossible, inasmuch as compression of the roots making up the cauda and compression of their respective segments in the lumbosacral cord may elicit practically the same symptoms. Below the conus, the anterior and posterior roots lie very closely grouped. They do not, however, by any means completely fill the

FIG. 239.—TERATOMA OF THE CAUDA EQUINA. (Spiller.)

canal, so that a tumor may attain considerable size without any objective or subjective disturbance. Among the most common types of tumors involving the cauda equina are endotheliomata, fibrosarcomata and sarcomata, while fibromata, myxomata, lipomata and gliomata are occasionally found (Table XVII).

Caudal Tumors.—While there are certain symptoms said to be characteristic of *caudal tumors* in general, these vary somewhat, according to whether all the fibers of the cauda are involved. When this is the case, there are, beside the root symptoms, complete motor and sensory paralysis of the lower extremities with loss of reflexes and, depending upon the level of the lesion, visceral anesthesia, incontinence of urine, and feces, and

TABLE XVII

TUMORS OF THE CAUDA EQUINA

(*Pathological Diagnosis*)

Fibroblastoma:		
Fibroma	2	
Fibromyoma	1	
Fibrosarcoma	6	9
Myxoblastoma:		
Myxoma	1	1
Lipoblastoma:		
Lipoma	1	1
Epithelioblastoma:		
Angiosarcoma	1	
Lymphangioma	1	
Endothelioma	8	10
Glioblastoma:		
Glioma	2	
Gliosarcoma	1	3
Unclassified:		
Hydatid cyst	1	
Sarcoma	5	6
TOTAL		30

impotence. Caudal tumors develop slowly. Excruciating pains in the hips, over the coccyx and in the distribution of the sciatic nerve, anesthesia, loss of reflexes in the lower extremities, accompanied later by paralysis and muscular atrophy in the affected regions, form the principal features in the clinical picture. The sensory disturbances ordinarily appear first, because, as pointed out by Müller, the sensory roots in this region are larger than the motor roots. Pain, unilateral at first, but sooner or later becoming bilateral, may exist for some time before other symptoms are observed. Irritation of the motor roots, however, may cause spasmodic contractions in the lower limbs, and there is often anesthesia on the posterior aspect of the thighs and on the dorsum of the feet. Motor and sensory paralyses appear late, and indicate that the tumor has attained considerable size. This stage can never be preceded, as in cases of tumors of the cord proper, by the Brown-Séquard syndrome. Referring to the tables of Raymond and Seiffer (Table XVIII), and to the diagram from Müller (Fig. 240), we see that the external genitalia, the perineum and the anus receive their sensory innervation from the lowest spinal roots; hence they become anesthetic when

TABLE XVIII

DISTRIBUTION OF LOWEST SPINAL NERVES IN BLADDER, RECTUM AND GENITALIA

	RAYMOND'S TABLE			Sensory Supply (According to Seiffer)
	Motor	Sensory	Reflexes	
Fifth lumbar. (Abd.)	Gluteus medius and minimus, tensor fasciæ, semimembranosus, semitendinosus, biceps.	Outer side of thigh.		External surface of leg, dorsum and sole of foot.
First sacral. (Ext. rot.)	Pyriformis, obturator internus, gemelli, gluteus maximus.	Posterior surface of thigh and leg.	Plantar.	External surface of leg, dorsum and sole of foot, outer part of posterior surface of leg.
Second sacral.	Tibialis anticus, peroneal muscles, center for erection.	Exterior surface of leg and foot, sensation of bladder and upper part of rectum.		Median part of posterior surface of thigh.
Third sacral.	Center of ejaculation, ischiocavernosi and bulbocavernosi.	Sensation of urethra, penis, and scrotum.		Penis, scrotum, vulva, perineum, and region of buttocks.
Fourth sacral.	Muscles of bladder.	Perineum, sacral region.	Ankle-jerk.	An oval area including the region of sacrum as far as the anus.
Fifth sacral.	Levator ani, sphincter ani.	Coccygeal region, anus.	Anal.	

these roots are compressed. The bladder, rectum and genitalia are almost invariably paralyzed in these cases, but this occurrence has little significance in topographical diagnosis, since there is the same result whether the pressure be imposed upon the roots near their exit from the cord or

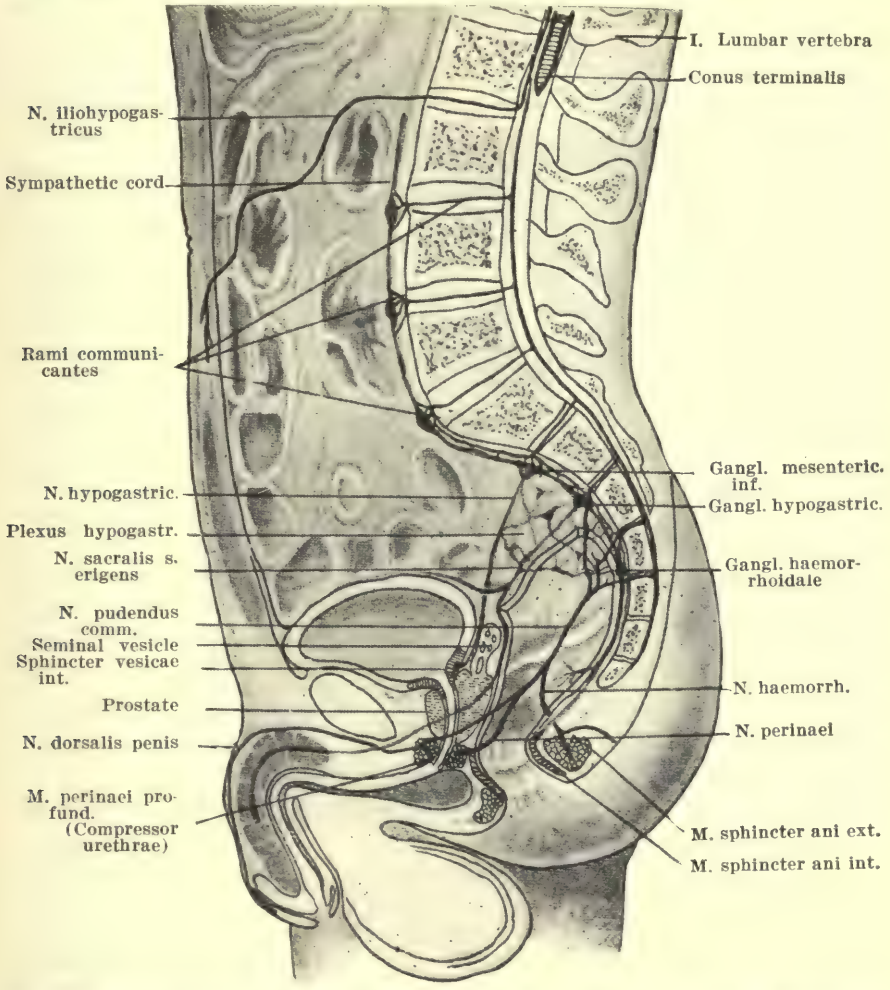

FIG. 240.—ANATOMICAL DRAWING SHOWING INNERVATION OF BLADDER, RECTUM AND GENITAL ORGANS. (After Müller.)

in the lower part of the cauda (Fig. 241). This paralysis, however, is one of the most constant of the symptoms and frequently takes place early in the course of the disease. Occasionally, the bladder and rectum are not paralyzed, although the other symptoms may have progressed almost to the final stage. This was illustrated in a patient upon whom I operated a little over a year after the symptoms first appeared.

A case illustrating some of the peculiarities of a tumor of the cauda equina. While there was some motor weakness and loss of reflexes there was little disturbance of sensation and no paralysis of bladder and rectum. Diagnosis confirmed by laminectomy at which a fibrosarcoma was found in the roots of the cauda equina at the level of the third lumbar vertebra.

The patient, a woman, *aet.* 59, was admitted to my service at the University Hospital, November 8, 1906 (File No. 1887). The pain, which was at first fluctuating in character, began in the left hip about two years before the patient's ad-

FIG. 241.—TUMOR OF LOWER PORTION OF CORD WHICH GAVE RISE TO TYPICAL SYMPTOMS OF CAUDAL LESION. (Jacobsohn.)

mission, in the course of a year becoming more severe and extending down the left leg, suggesting sciatica. Contemporaneously, she had sharp pain in the sacral region, extending up to, but not above, the lumbar region. The pain was paroxysmal, with marked remissions, and so intense as to be controlled only by large doses of morphin. Later, shooting pains began in the right lower extremity, and five weeks before admission there was, with the exception of the movements of the toes, complete paralysis of both lower extremities, but no vesical or rectal disturbances and no anesthesia.

Physical Examination.—Pressure over the lumbar vertebrae gave more pain than anywhere else in the spinal column, but movements of the lower limbs caused no pain in the spine. There were no motor, sensory or reflex disturbances in the upper extremities. *Sensory Disturbances.* There was no sensory disturbance even in the perineum and around the anus. *Motor Disturbances.* Lower extremities:

Muscular power was very weak at the hips. The right knee could be raised from the bed better than the left, although showing marked loss of power. The movement of the toes was performed fairly well on either side, though weakly. Flexion of the right ankle was performed very well, but there was little power in the left ankle. *Reflex Disturbances.* There was complete loss of patellar and Achilles tendon reflexes on each side.

Laminectomy, November 10, 1906. Through an incision in the midline with its base at the lower border of the first lumbar vertebra, I exposed the structures from the first to the fifth lumbar vertebrae. Upon the removal of the laminae and transverse processes, the dura was opened and a tumor found at the level of the third lumbar vertebra. Associated with the tumor, which proved to be a fibrosarcoma (Fig. 242), was a cyst within the roots of the cauda equina, 1.25 cm. above the termination of the conus. The cyst, 2.5 cm. long and 1.25 cm. wide, shaped like an almond, did not involve the roots of the lower part of conus, hence the escape of bladder and rectum.

FIG. 242.—FIBROSARCOMA AND BLOOD CYST IN THE CAUDA EQUINA. (University Hospital, File No. 1887.)

In three cases with operation recorded by Elsberg and Collins, large reddish-brown tumors were found within the dura, filling the entire lower part of the canal, surrounding the roots of the cauda and reaching upward to the conus (Fig. 243). They were benign, did not infiltrate the dura or the vertebrae, and in this way differed from some of the intradural sarcomata reported by Spiller, Schultze and others. Spiller reports a case presenting the typical picture of caudal tumors in which numerous osteosarcomata, both extradural and on the roots within the dural cavity, were revealed at necropsy (Fig. 244). The peculiar features about the three cases of Elsberg and Collins, the authors believe, are certain variations in the symptom-complex, namely, the relatively late appearance of the vesical and rectal symptoms, and the slight sensory disturbance. The typical anesthesia in the perineum, genitals and around the anus was incomplete, ill-marked, or absent, while in each case the tumor was so large that it filled the entire lower portion of the canal. Such absence or incompleteness of anesthesia has been explained by Klieneberger on the grounds that while the sensory roots are larger than the motor roots in this portion of the cord, the sensory fibers possess a much greater resistance. As to the late appearance of the disturbances of the bladder and rectum, Spiller and van Gehuchten are of the opinion

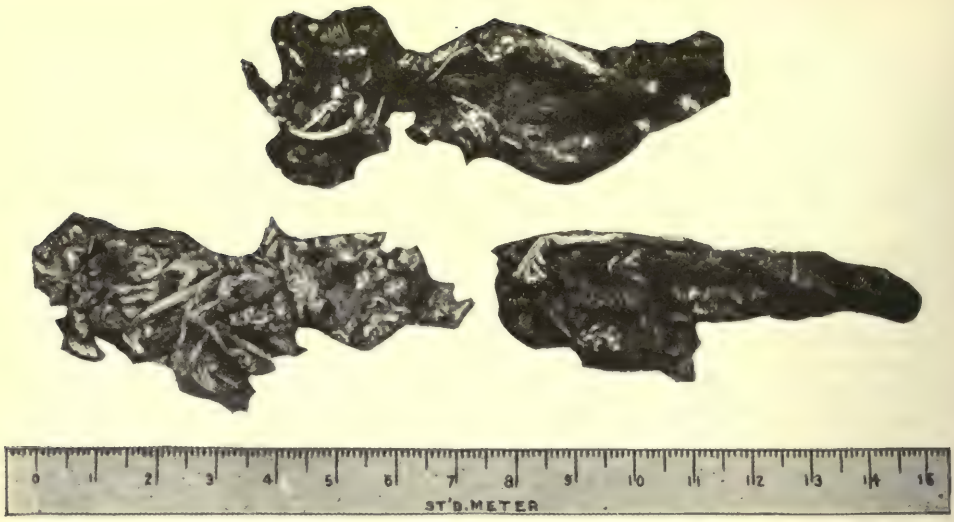

FIG. 243.—TUMORS OF THE CAUDA REMOVED AT OPERATION. (Elsberg and Collins.)

FIG. 244.—OSTEOSARCOMATA IN THE CAUDA EQUINA. (Spiller.)

that bladder and rectal symptoms need not appear early in cases where there is intradural pressure on the roots of the cauda, and my own experience leads me to concur in this opinion. van Gehuchten, as a result of clinical and experimental observations, believes also that the bladder, rectum and genital organs may retain at least some function even after all the roots of the cauda are affected. He accounts for this by the existence of reflex centers for these organs outside of the cord. Indeed, the primary centers are in the hypogastric plexus of the sympathetic system; but they also have centers in the conus, and these must be intact to function normally.

Oppenheim divides affections of the cauda into four groups, according to their topographical location. The first group at the level of the second lumbar vertebra involves the entire cauda, and gives rise to atrophic paralysis and anesthesia in the lower extremities, paralysis of the bladder, rectum and genital organs, and loss of reflexes. The second group, including lesions from the third to the fifth lumbar vertebrae, is characterized by atrophic paralysis and anesthesia in the distribution of the sciatic nerve, the crural and obturator being unaffected in these cases, and the patellar and cremasteric reflexes usually remaining intact. In the third group, lesions from the fifth lumbar to the second sacral vertebrae, the sciatic nerve is only partially affected. In the fourth group, comprising lesions below the second sacral vertebra, motor disturbances in the lower extremities are entirely lacking, the clinical picture consisting of isolated vesical, rectal and genital paralyses, with perianogenital anesthesia in the horseshoe-shaped area (Fig. 245). The root symptoms, pain and spasmodic contractions may be present in any of these types in the early stage.

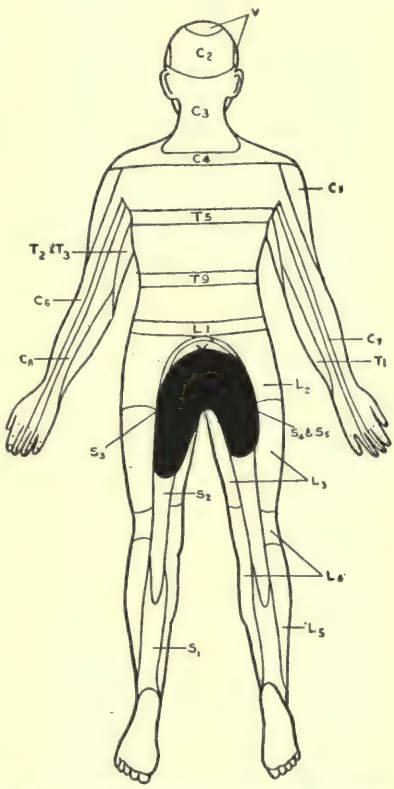

FIG. 245.—HORSESHOE-SHAPED AREA OF ANESTHESIA CAUSED BY TUMOR OF THE CAUDA EQUINA.

Tumors of the Conus.—Pain is frequently lacking in tumors involving only the conus, and when present it is not a prominent feature. Since the diameter of the cord at this point is not great, practically all the tracts are involved at once, and anesthesia and paralysis of the bladder and rectum occur very nearly at the same time (Spiller). Inasmuch as

the motor centers for the lower extremities are situated higher in the cord, the motor disturbances are limited to the bladder, rectum and genitalia. There is usually symmetrical impairment of sensation in these cases, the integuments of the penis, scrotum, perineum, anus, the inner aspect of the buttocks and posterior aspect of the thighs being rendered anesthetic. Decubitus is very marked in the final stage. The accompanying table (Table XIX) of symptoms by Jacobsohn is especially helpful.

TABLE XIX

Conus	Cauda
1. Pain lacking or slight.	1. Violent pain in the sacrum, perineum, and lower extremities.
2. Sensory disturbance frequently dissociated.	2. Sensory disturbance almost never dissociated.
3. Motor disturbance most prominent symptom.	3. Motor paralysis lacking, or appearing only late.
4. Paralysis and sensory disturbance distributed symmetrically.	4. Disturbances less symmetrical.
5. Achilles reflex lost, patellar sometimes increased.	5. Achilles reflex lost, patellar diminished.
6. Tendency to decubitus and trophic disturbances.	6. Less tendency to decubitus and trophic disturbance.

With lesions of the conus, as will be seen from this table, pain is either lacking or unimportant; while a lesion affecting the cauda generally causes violent pains in the sacrum, bladder, perineum, anal region and in the distribution of the sciatic nerve. The longer course of caudal tumors is due, at least in part, to the larger space in which they develop. Asymmetry of the symptoms is in favor of involvement of the cauda; while on the other hand, trophic disturbances appear earlier and more commonly with tumors of the conus. Structural changes in the vertebrae are not so frequent as one might expect from the size of these growths. While the bladder, rectum and genitalia are innervated in part by fibers from the conus, the third to the fifth sacral segments, according to van Gehuchten, paralysis of these organs may also be caused by pressure on the roots further down the canal (Fig. 237). While the fibers from the two upper sacral segments innervate the muscles of the foot, the conus fibers, the third to the fifth sacral segments, have nothing to do with peripheral motility. When the conus itself is involved, anesthesia will be found in the horseshoe-shaped zone in the region of the anus and posterior surface of the thigh supplied by its cutaneous sensory fibers.

The tumors which are so extensive as to involve both cauda and conus (Fig. 246) present a combination of the symptoms above described, as in the following case reported by Leszynsky:

The patient, a woman, *aet.* 49, exhibited the typical symptoms of a tumor involving the entire cauda; at the operation a large mass, filling the entire sacral canal and extending up over the conus, was exposed and partially removed. She had complained for nine years of characteristic root pains in the distribution of her left sciatic and anterior crural nerves, and four years later the right lower extremity was affected in a similar manner. The legs became weak and there was a sensation of constriction at the level of the lower thoracic region. Finally, there was complete paralysis of the lower extremities with bilateral foot-drop, loss of patellar, Achilles and plantar reflexes, and paralysis of the bladder and rectum. Hypalgesia and thermal anesthesia extended several centimeters above the umbilicus. Far advanced as these symptoms showed the condition to be, Elsberg performed a palliative operation, which, however, produced no improvement and the patient survived only three months. At autopsy, a glioma was found, involving the cauda and filling the entire sacral canal.

FIG. 246.—FIBROSARCOMA INVOLVING THE CONUS AND CAUDA EQUINA. (Spiller.)

TUMORS OF THE VERTEBRAL COLUMN.—Tumors arising from the vertebral column are of far more frequent occurrence than those arising from the meninges or cord, and carcinoma, almost invariably metastatic, far outnumbers the other types, as will be seen from Schlesinger's analysis of 107 cases (Table XX, p. 544).

These tumors take their origin most often from the periosteum of the vertebral body or from the cancellated structure, and, in one-third of the cases, from the arches or other processes. Tumors originating from the vertebral bodies may damage the roots and the spinal cord directly by compression, indirectly by the resulting deformity of the vertebral column, or the compression may determine an edema of the cord. Occasionally very malignant tumors erode the dura and invade the cord, but this is rare. Since the majority of these tumors, whether primary or secondary, arise in the vertebral bodies, they involve the roots either in the spinal canal or in the intervertebral foramina first by compression and

TABLE XX

TUMORS OF THE VERTEBRAL COLUMN

Carcinoma	54 cases
Sarcoma	34 "
Osteoma	10 "
Myeloma	6 "
Chondroma (Chondrosarcoma)	2 "
Myxoma	1 "
	107 cases

later by infiltration. In most instances, both anterior and posterior roots are affected, and if pressure be unrelieved, the cord itself becomes involved. In the spontaneous arrest of growth, which occasionally takes place with benign tumors such as exostoses, the cord and roots may escape pressure.

In the early stages, the symptoms are those of root irritation and root compression, and these may continue even after the cord has become compressed. The pain, which is paroxysmal in type, is often described as a sharp, burning sensation, and is so severe at times as to be uninfluenced by morphin. Depending, of course, on the location of the tumor, pain may be referred to the distribution of the brachial plexus, the intercostal nerves, or the lumbosacral plexus. At first unilateral, it soon becomes bilateral and is associated with areas of hyperesthesia and paresthesia. Even after anesthesia becomes established, pain may continue in the form of anesthesia dolorosa. Should the cervical sympathetic cord be involved, as in tumors of the lower cervical vertebrae, inequality of the palpebral fissures, contracted pupil, retraction of the eyeball and flushing of the face will be added to the picture. Disturbances of the anterior roots, more common to tumors of the cervical and lumbar region, may be synchronous with those of the posterior roots and cause muscular twitchings and spasms. Often the anterior roots are not affected until much later, and sometimes not at all. At a comparatively early stage in most instances, the cord becomes compressed either directly by the tumor or by the accompanying deformity of the vertebrae. In the terminal stage, the paraplegia becomes complete below the level of the lesion, involving both bladder and rectum, and differing from other compression paralyses in that it is almost invariably accompanied by severe pain, the paraplegia dolorosa of Cruveilhier. Atrophic paralysis is usually found at the level of the lesion, and spastic paralysis below it.

Contrary to the sequence of symptoms in tumors arising in the cord or the meninges, symptoms referable to the spinal column itself are the first to appear when the lesion is of vertebral origin. Thus we look for circumscribed pain, tenderness on pressure, stiffness or rigidity, and more or less deformity. In some it may be a slight scoliosis, in others the deformity is a rounded kyphosis of slow development, quite different from the angular kyphosis of tuberculous spondylitis. The sudden appearance

of a deformity with evidence of grave pressure symptoms arouses suspicion of a pathological luxation, fortunately a rare event. Provided the tumor does not involve the canal, there may be an absence of motor paralysis and anesthesias. This is aptly illustrated by the following case:

A case of sarcoma of the vertebral body in which the chief complaint was unilateral pain in the territory of the seventh and eighth intercostal nerves and, because of the absence of other motor and sensory disturbances, the case was clinically misinterpreted and regarded as a case of intercostal neuralgia.

The patient, a man, *aet.* 52 (File No. 31568), was admitted to my service in the University Hospital, April 4, 1916. For the two years prior to admission he had suffered from constantly increasing pain in his lower right thoracic region. The area of pain was bounded posteriorly by a vertical line from the sixth to the eighth thoracic vertebrae, inclusive, then around the trunk on the right side to a vertical line anteriorly, including the sixth, seventh and eighth ribs at their junction with the sternum. In front the lower border corresponded with the costal margin; the upper border was just below the nipple line. Because of the circumscribed distribution of the pain, the patient had been admitted under a diagnosis of intercostal neuralgia.

The family history was negative, as was also the past medical history of the patient. There was no paralysis nor were there any anesthesias or paresthesias. The Wassermann examination of both blood and spinal fluid was negative. An x-ray examination showed a lesion involving the seventh and eighth thoracic vertebrae. The only points of interest in the physical examination were a mass in the right iliac fossa, possibly a tumor of the cecum, and the blood count showing 3,490,000 erythrocytes and 50 per cent hemoglobin.

On April 11, 1916, I decided to section the seventh intercostal nerve on the right. On exposure of the intercostal space there was noted a pale granulation tissue, chiefly outside the transverse processes overlying the laminae, which suggested neoplasm. The intercostal nerve could not be found, although the whole intercostal space was liberally exposed and further exploration was abandoned because of the hopeless nature of the case.

An x-ray examination of the chest, subsequent to the operation, discovered evidence of metastasis to the lungs, especially at the roots, as well as a destruction of part of the eighth rib and possibly others. The pathological examination of the tissue removed at the operation determined the condition as one of sarcoma. The patient failed rapidly and was removed to his home in the early part of May, 1916.

Because the skeletal changes appear early, the roentgenogram ought to be helpful as an aid to diagnosis: it is so in some cases, but not always depending somewhat upon the variety of growth. Thus a periosteal sarcoma might not be revealed at all in the roentgenogram if there had been no bone destruction, whereas the destructive influence of a carcinoma is readily detectable. Schultze reports a case in which the absence of pain and a negative x-ray led him to suspect an intramedullary tumor, but at the operation an enchondroma of half of the arch and body of the third thoracic vertebra was found. The case is particularly interesting be-

cause the patient, a woman, *aet.* 65, had been operated upon four years before by Kocher for struma of the thyroid (no malignancy). Gradual paresthesia had developed in the lower extremities, then a slight anesthesia, weakness of the left leg, spastic paraplegia and a slight kyphosis in the upper thoracic region.

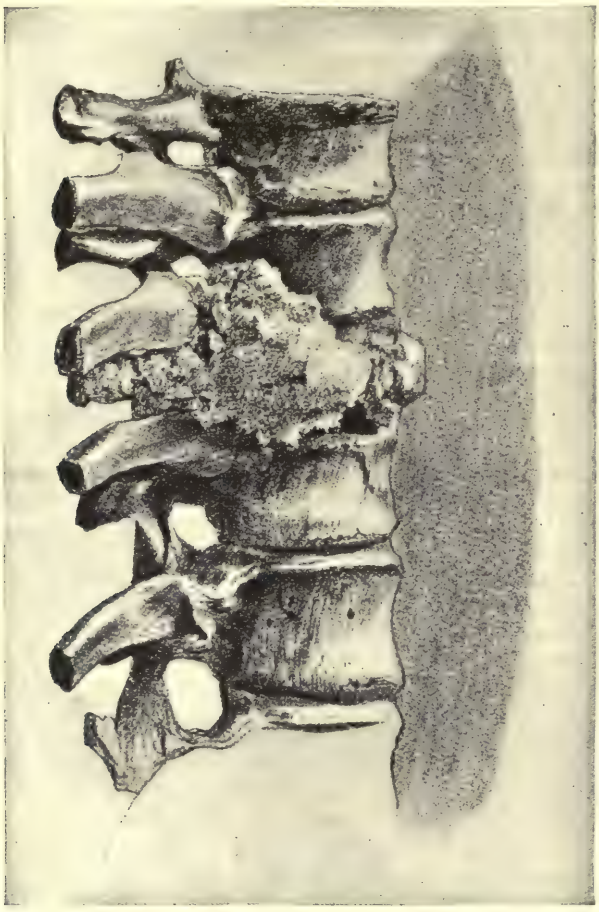

FIG. 247.—ENCHONDROMATOUS OSSIFICATION OF THE SPINAL COLUMN AND RIBS, WITH INVASION OF THE SPINAL CANAL AND NARROWING OF ITS LUMEN. (Schlesinger.)

Allowance must be made, therefore, for negative x-ray findings, and too much faith must not be placed in the root symptoms. While pain is frequently the predominating symptom in vertebral tumors, it may be entirely lacking, as it was in the case of Schultze above quoted, and in one of Förster's cases; in the latter the patient had never had any pain, and at the operation a tumor was found in the arch of the fourth thoracic vertebra. He did have a disturbed sensation up to a point 4 cm. below the nipple line, increasing weakness of the lower extremities, and total spastic paraplegia with exaggerated patellar and Achilles tendon reflexes, ankle clonus, positive Babinski and Oppenheim reflexes. The distinction, therefore, between tumors of vertebral and those of meningeal and medullary origin is not always sharply defined. So, too, some difficulty may be encountered in differentiating vertebral tumors from caries of the spine. A primary growth elsewhere should arouse a suspicion of tumor rather than vertebral caries or spondylitis. In caries the deformity is more angular and later on the process is attended with abscess forma-

TABLE XXI

VERTEBRAL TUMORS (PRIMARY)

Pathological Diagnosis	Cervical	Thoracic	Lumbo-sacral	Total
Chondroblastoma:				
Enchondroma	2	3	1	6
Chondrosarcoma	..	1	1	2
Osteoblastoma:				
Osteoma	..	2	2	4
Osteofibrosarcoma	..	..	1	1
Endothelioblastoma:				
Dural endothelioblastoma:				
Endothelioma	1	1	..	2
Myeloma:				
Myeloma	..	1	2	3
Melanoblastoma:				
Melanoma	..	1	..	1
Epithelioblastoma:				
Carcinoma	..	1	..	1
Inflammatory-reaction processes:				
Tubercle	..	..	1	1
Unclassified:				
Sarcoma	4	10	7	21
Not stated	..	2	1	3
TOTAL	7	22	16	45

tion. Pressure symptoms, severe and enduring, are the rule rather than the exception with tumors; with spondylitis they are the exception rather than the rule. Localized tenderness would be more pronounced in spondylitis.

Primary Tumors of the Vertebrae.—These are seldom benign. According to Bérard, the cases of osteoma, exostosis, chondroma, myeloma, myxoma and fibroma altogether do not outnumber sarcoma. This statement is borne out by the accompanying table (Table XXI) based on 45 cases of primary vertebral tumors in which the diagnosis was confirmed at operation. While osteoma and exostosis grow slowly, and seldom attain sufficient dimensions to compress the cord, fibroma and enchondroma often assume larger proportions and invade the vertebral canal (Fig. 247). Hydatid cysts, much more common, by the way, in Germany than in the United States, are of rapid growth, encroach upon the space

in the spinal canal, compress, but seldom invade the cord. Primary sarcoma in most cases springs from the vertebral body either peripherally or centrally, more rarely from the arches or spinous processes. Sarcomata, the central variety especially, are so destructive that the vertebral bodies become compressed and flattened and the tumors break through the dura more frequently than any other type of tumor (Fig. 248). One should not wait until the diagnosis is established beyond a shadow of doubt to resort

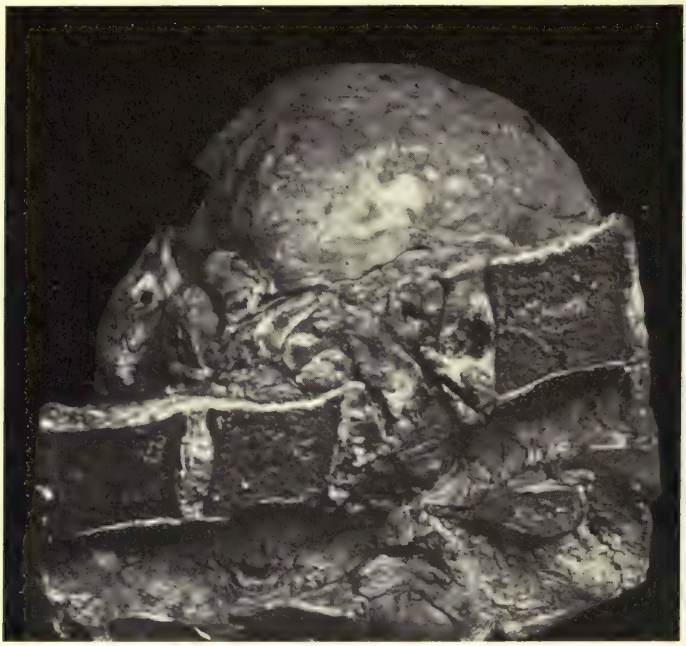

FIG. 248.—PHOTOGRAPH OF SARCOMA OF THE BODY OF A VERTEBRA FROM A SPECIMEN IN THE ARMY MEDICAL MUSEUM AND LABORATORY, WASHINGTON, D. C.

to an exploratory operation. The suspicior of a new growth is quite sufficient a warrant; differentiation between the operable and inoperable growths is often impossible, and delay often spells disaster. There is no advantage in delaying operation until the tumor, whether it be benign or malignant, encroaches upon the cord, provided the diagnosis is reasonably sure. The hydatid cyst may rupture spontaneously on the surface, but more often it invades the spinal canal, and pressure is relieved only by operation.

Metastatic Tumors.—These are found chiefly in persons beyond middle life, more commonly in women than in men, in women most frequently as a sequel to primary carcinoma of the breast, in men as a sequel to carcinoma of the prostate. On various occasions the primary tumor is in the esophagus, thyroid, uterus or stomach. The origin of 59 metastatic

carcinomata will be seen in the following table compiled by Schlesinger (Table XXII):

TABLE XXII[1]

Mammary	10 cases
Esophagus	9 "
Thyroid	9 "
Uterus	6 "
Bronchus	5 "
Stomach	4 "
Prostate	3 "
Gall bladder	2 "
Sinus pyriformis	2 "
Bladder	1 case
Ovary	1 "
Sigmoid flexure	1 "
Rectum	1 "
Kidney	1 "
Adrenals	1 "
Larynx	1 "
Pancreas	1 "
Origin not given	1 "
TOTAL	59 cases

In Table XXIII an analysis has been made of the primary seat in 13 metastatic tumors exposed at operation.

TABLE XXIII

Origin	Cervical	Thoracic	Lumbo-sacral	Total
Epithelioblastoma:				
(a) Adenoma (Thyroid)	..	2	..	2
(b) Carcinoma (Breast)	1	4	3	8
(c) Carcinoma (Prostate)	..	..	1	1
Unclassified:				
Sarcoma	..	1	1	2
TOTAL	1	7	5	13

Metastatic vertebral tumors comprise more than half of all spinal tumors. If carcinomata, they are apt to start in the cancellated structures of the vertebral bodies, and by a more or less rapid process of erosion, they soon

[1] Schlesinger states that five cases were added after Table XX was compiled. Hence 59 carcinomata instead of 54.

invade the sheaths of the nerve-roots in the intervertebral foramina. The cortex of the bone, however, may be left intact for some time, under which circumstances the tumors will not be palpable. On the other hand, sarcomata, arising as they often do in the periosteum of the bodies or occasionally in the arches or spines, may be readily detected by palpation. Sometimes, especially with carcinoma, the vertebral body or bodies will suddenly collapse with consequent shortening, deformity and compression of the cord.

Between 70 and 80 per cent of the metastatic tumors are carcinomata, and their favorite location is either the thoracic or the lumbar region. Of 22 cases of secondary vertebral tumors, 18 or 82 per cent metastasized from the mammary gland, and of 339 breast cancers, the vertebral column was later involved in 72 (Potel and Veaudeau). The time between the appearance of the primary and the metastatic growth is variable, but in many instances surprisingly long, varying from one to eleven years. Metastasis takes place either through the circulation or the lymphatics, though the latter is the most common route. The first and dominating feature is excruciating pain, associated often with a girdle sensation, as in a case upon which I recently operated.

A case of metastatic carcinoma involving vertebra and cord, illustrating the excruciating pain as a characteristic feature of this lesion. Diagnosis confirmed by laminectomy at which a portion of the tumor involving the dura was removed with relief of pain.

The patient, a woman, *aet.* 43, was referred to my service at the University Hospital, May 9, 1912 (File No. 11263). Four years before admission, she had undergone a complete amputation of the breast for carcinoma and suffered no untoward symptoms until three years later, when she began to have lancinating pains in the back beneath the shoulder blades and extending to the waist. The pains, severe at first, gradually became less intense, but eight weeks prior to her admission, they returned in their old severity, and this time extended down the outer surface of the left arm. Weakness in the lower extremities had been slowly developing until, at the time of admission, voluntary movement was not possible in either leg. and control over the bladder and rectum was lost. The girdle sensation at the level of the mid-epigastrium, which had been present at first, disappeared, and was replaced by hypesthesia and later by anesthesia, so that when she came to the hospital, anesthesia was complete below this level. The upper extremities were entirely normal.

Physical Examination.—Sensory Disturbances. Thorax and abdomen: On the right side extending from the tip of the ensiform cartilage anteriorly to the lower border of the tenth thoracic vertebra posteriorly, tactile sensation was lost; the same limitation was present on the left. Sensation for heat, cold and pain and the determination of two points of a compass, was lost to about the same level, the difference in the several types being so small that special charting was unnecessary (Fig. 249). *Motor Disturbances.* There was absolute loss of power from the thorax downward. *Reflex Disturbances.* On both sides patellar and Achilles tendon reflexes were markedly exaggerated and the Babinski phenomenon typical. Ankle clonus was present on both sides, but not marked.

Laminectomy and *Rhizotomy,* May 11, 1912. Endotracheal insufflation anesthesia. Through a curved incision, the spinous processes of the sixth, seventh and eighth thoracic vertebrae were exposed and removed. In separating the muscles from the laminae of the seventh vertebra, an area of softening was found. The laminae of these three vertebrae were removed and the following conditions noted: first, an extensive malignant infiltration of the seventh vertebra; secondly, a patch of carcinomatous tissue on the posterior and lateral aspects of the dura on a level with the seventh vertebra; thirdly, the seventh and eighth spinal roots, both anterior and posterior, were mostly destroyed by the carcinomatous process (Fig. 250). That

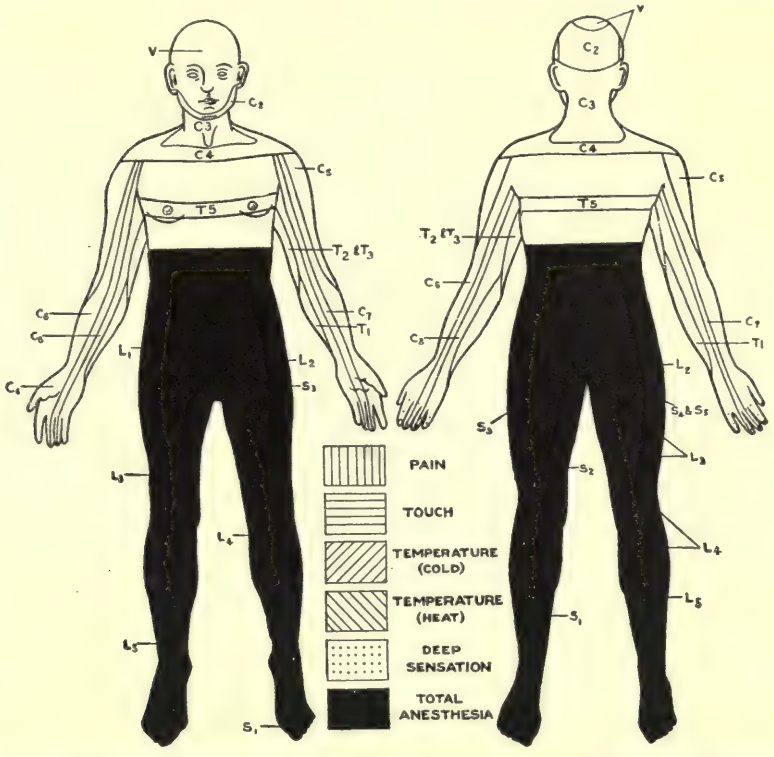

FIG. 249.—CHART OF SENSORY DISTURBANCES IN CASE OF METASTATIC CARCINOMA INVOLVING VERTEBRA AND CORD. (University Hospital, File No. 11263.)

portion of the dura which was the seat of the malignant infiltration was removed, and what remained of the posterior roots of the seventh and eighth segments were divided. Oozing from the area of bone involved was quite extensive during the operation and necessitated the introduction of two small wicks of gauze, the ends of which were brought out at either angle of the wound.

Convalescence was uneventful, and the patient was relieved of pain during the year she survived.

There are many instances on record where deposits of thyroid tissue have been found in the osseous system, including the vertebral bodies. These masses of thyroid tissue may produce colloid, replace more or less

of the bone element, and, while having the properties of malignant growths, present histologically the picture of a benign lesion. Siegel reports a case in which an extradural tumor with typical struma tissue (Fig. 251) was removed from a woman of thirty-three who had had a goiter for six years, and while the enlargement was to all appearances benign, there had never been any histological examination, and there was nothing to eliminate the

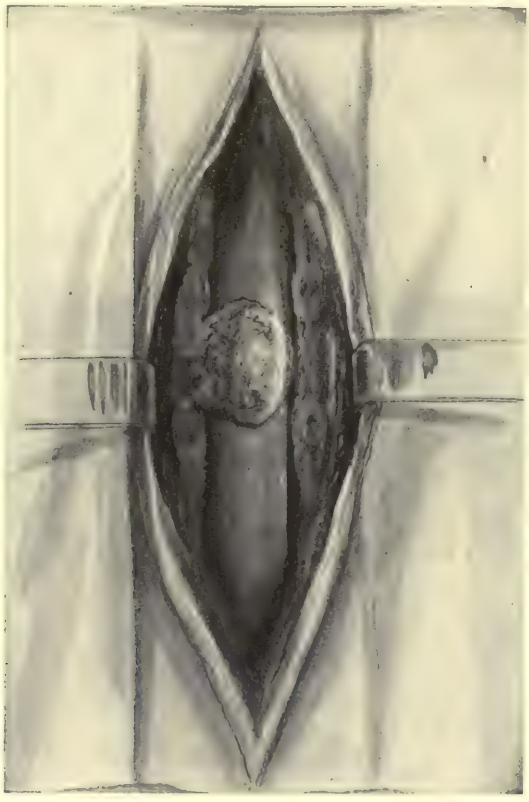

FIG. 250.—METASTATIC CARCINOMA INVOLVING THE SEVENTH THORACIC VERTEBRA, THE SEVENTH AND EIGHTH SPINAL ROOTS AND ADJACENT POSTERIOR AND LATERAL ASPECTS OF THE DURA. (University Hospital, File No. 11263.)

possibility of secondary malignant changes. Jaeger also has reported a vertebral tumor with the structure of a typical colloid struma, following what was apparently a struma of the thyroid, but the diagnosis was not confirmed by operation or histological examination. It is well to bear in mind the possibility of this relationship between struma and metastasis to bone in patients who present symptoms of involvement of spine and cord, although many doubt the theory of benign metastasis.

Differential Diagnosis.—The diagnosis of spinal tumors is often an easy matter, especially when the clinical course conforms to type. Yet,

other spinal lesions may mimic spinal tumors in so many particulars that a differential diagnosis may be attended with difficulty.

The roentgenogram we have found of little assistance in detecting tumors, except those originating in or later invading the vertebral column, and even here it is frequently negative.

The chemical, cytological and bacteriological examination of the cerebrospinal fluid has proven of value in determining the presence or absence of a space-resisting process in the spinal canal, but how much it can be relied upon to determine the character of the lesion is still open to

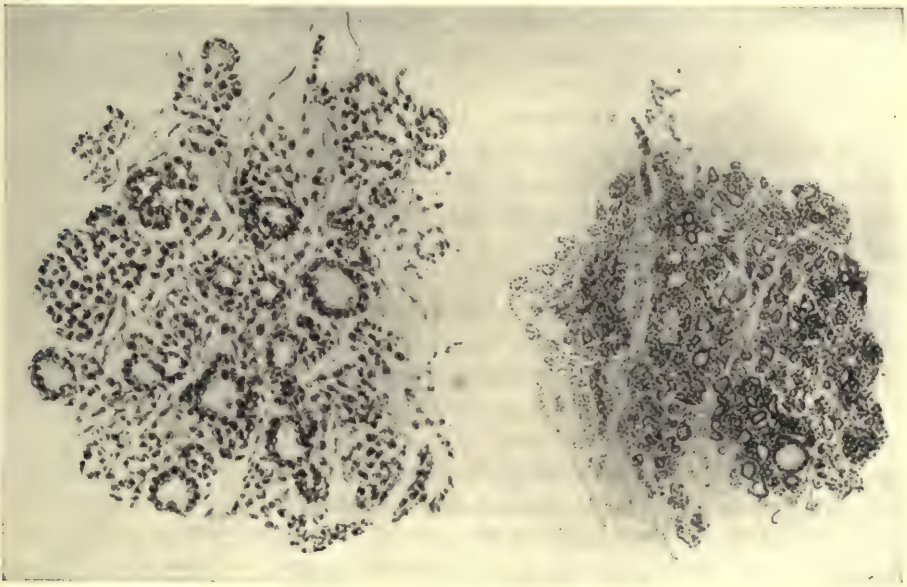

FIG. 251.—AN EXTRADURAL TUMOR SHOWING TYPICAL STRUMA TISSUE IN A PATIENT WITH A GOITER OF SIX YEARS' DURATION. (Siegel.)

question. In 1903, Froin first described the so-called "compression syndrome," which included xanthochromia, increase in the amount of albumin, and in the number of cells, and Sicard, Bard, Villaret, Rindfleisch, Reichmann, Raven *et alii* have made further contributions to the subject. Küttner found this syndrome in two cases of caudal tumors, and regards it as a measure of importance in the diagnosis. Klieneberger described this syndrome as pathognomonic of a space-restricting process in the lower portion of the spinal canal, but these changes have been found to accompany lesions at higher levels. An increase in the percentage of albumin has been found to be proportionate to the degree of cord compression, although the fluid may not come from the site of compression. Lymphocystosis points to a compression, but is more suggestive of involvement of the meninges. While Schönbron, Grund, Heilig, and others

have given prominence to these changes as characteristic of spinal tumors, it may at least be said that the syndrome has been found in processes of quite a different nature, such as tuberculous spondylitis and certain forms of meningitis. When, however, this so-called "compression syndrome" accompanies other suggestive symptoms, it may be regarded as of some corroborative importance.

It is particularly hard to make an accurate diagnosis in the early stage when the root pains are the predominating, if not the only, feature, as pain and paresthesia are present in many other diseases of the spinal cord. The pain of tumors is characterized by its persistence and severity, invariably aggravated by motion, and without the tender spots of neuritis. Signs of irritation and degeneration of the spinal roots, accompanying disturbances of the cord, are particularly suggestive of tumor when both are unilateral in their expression. However, many conditions other than tumor may cause compression, such as spondylitis, hypertrophic arthritis and meningitis. A disseminated sclerosis as well as syringomyelia and spinal syphilis will often cause paraplegia very like that accompanying tumors, so that occasionally a differential diagnosis is impossible. In the matter of syphilis, other symptoms of the disease are usually present and the serological investigation should help to establish the diagnosis. Schultze has seen two such cases in which there was so much doubt that an exploratory laminectomy was performed, but no tumor was found in either case. The roentgenogram was negative in both instances, as was also the Wassermann reaction.

There should be no difficulty in recognizing tuberculous spondylitis, but it is well to remember that it may be accompanied by many of the same symptoms as tumors, such as the root pains and the paralyses, but in tuberculous spondylitis the process is more rapid, at least the signs of cord disturbance follow more quickly the root symptoms than is usually the case with tumors. The symptoms are rarely unilateral in tuberculosis; fever and peptonuria are frequently present, and occasionally tuberculosis of other organs. Added to the evidence of involvement of the cord and roots are the signs of an inflammatory focus in the vertebral column: the localized tenderness, the fixation and later the characteristic kyphosis. The roentgenogram is always of value when tuberculous caries is suspected, as it may show the tuberculous focus in the body of the vertebra before the characteristic deformity develops. As tuberculosis is much more frequent than tumor, it should be eliminated before the possibility of tumor is entertained; on the other hand, tumors should always be under consideration in cases of paraplegia with an obscure etiology.

The similarity between the symptom-complexes of circumscribed serous meningitis and tumors is still more striking. Ordinarily in cases of meningitis the symptoms are more diffuse and their progress slower, with even a tendency toward remission. Hence, the symptoms, especially the

paralysis and reflex disturbances, are more or less vacillating in character. The essential differences may be summarized as follows: In tumor there is a more or less distinct limitation of pain to the distribution of a sensory nerve or nerves passing through the involved level, whereas this limitation fails in chronic meningitis, where we frequently find the sensory manifestations most diffuse in topography. For the same reason motor disturbances and trophic changes, such as atrophy and cutaneous eruptions, are likely to be much more diffuse in chronic meningitis than in spinal tumors.

It sometimes happens that associated with tumor there may be circumscribed collections of fluid. If, when the dura is incised, the fluid gush forth as though under great pressure, and the meninges appear normal, one should think of tumor rather than of meningitis. Pachymeningitis cervicalis hypertrophica, first described by Charcot in 1869, often simulates spinal tumors, and I have found it the most confusing of all spinal lesions in the matter of differential diagnosis. The lesion is usually syphilitic in origin, the course of the disease is of slower progress, often extending over periods of ten or more years. The root symptoms alone may be present for a long time, even after the process involves a large segment, before the cord symptoms appear. The process extends up and down the cord, including its entire circumference and may be attended with a fixation of the corresponding segment of the spine not observed with tumors. Meningitis chronica fibrosa is an infiltrating process involving and fusing all three membranes; it is seldom mistaken for tumor, although it finally causes compression of the cord. It should be remembered that in the late stages of pseudoleukemia lymphoid deposits may occur in the spine and in the structures within the vertebral canal. These lesions should be suspected when intense and obstinate referred pains are present and can be explained in no other way. In such cases the roentgenogram may show areas of rarefaction in the vertebrae.

Topographical Diagnosis.—When the diagnosis of tumor has been definitely established, whether it be intramedullary, extramedullary or vertebral, the most important step, preliminary to a successful operation, is an accurate localization. At what level is the tumor situated, and what laminae must be removed for exploration? The answer to this question involves a most careful analysis and interpretation of the clinical signs, the correlation of the sensory, motor, reflex and other phenomena with their proper source in the spinal cord and roots. There are many well-known anatomical and physiological facts upon which to draw. On account of the relatively small space in which the tumor must develop, it rapidly involves successive segments, often both integuments and the cord itself, and various aspects of the cord. As Mills has pointed out, "a tumor which destroys the trophic centers for the arm in the anterior cornua might exert sufficient backward pressure to paralyze the motor tracts

running to the leg; or a cervical tumor might produce symptoms wholly observed in the legs." We must also take into account the fact that the relative position of segments and vertebrae may vary, also the many eccentricities which are the result of anatomical and physiological, as well as pathological, conditions. There are certain deductions that we may draw from the clinical data presented by any given case.

With a thorough knowledge of the peripheral course and distribution of the sensory nerves, it is possible to trace the symptoms of paresthesia, hyperesthesia, pain, hypesthesia and anesthesia, the manifestations of perverted or lost sensation, back to their source in the posterior roots and spinal cord (Fig. 252). As we have already seen, sensory disorders may be unilateral or bilateral, depending upon whether the lesion still involves only one side, or has become transverse; sometimes all types of sensation are disturbed, sometimes only a certain group. But however this may be, there are always at the upper level of the lesion certain sensory disturbances caused by irritation or compression of the involved posterior roots, or of sensory fibers in the cord, and below this level the various kinds of deep and superficial sensations are involved to a greater or less degree through interruption of sensory conduction in the cord. This anesthetic area varies according to the location and extent of the lesion. If the lesion be unilateral, the sensory disturbances will be confined for some time to one side, while in transverse lesions there is almost invariably complete loss of sensation below the site of the lesion.

While it is generally assumed that the upper level of anesthesia corresponds to the peripheral distribution of the posterior roots involved, there is a very real danger of locating the tumor *too low,* when the area of anesthesia alone is considered. Starr states that in the thoracic region the tumor is situated 10 cm. higher than the level of anesthesia on the back. Horsley advises performing the laminectomy 8 to 10 cm. above the upper border of the anesthetic zone; Leyden and Goldscheider laid down the rule that the tumor should be located two intercostal spaces above the upper level of anesthesia. One should also bear in mind the principle brought out by Sherrington that any one particular area of the skin receives its innervation from three to five segments. Thus, a region of complete anesthesia indicates that the conductivity of at least three roots has been destroyed. The author has never, in an exploratory laminectomy, had to enlarge the opening downwards in searching for a tumor, but always upwards. It has been my practice first to select the lowest laminae to be removed, or in other words, to determine upon the lowest point of exploration. This corresponds to the lower segment represented in the anesthetic zone. Three, four or five laminae above the level are removed until the exploration is completed. Great caution is needed in interpreting the area of anesthesia in the lumbar and sacral regions, inasmuch as the roots run so obliquely in the lower portion of the spinal canal that the cord-seg-

ment from which one of these roots arises is a considerable distance above its point of exit from the spinal canal. It may, therefore, be difficult to determine whether the upper level of anesthesia corresponds to compres-

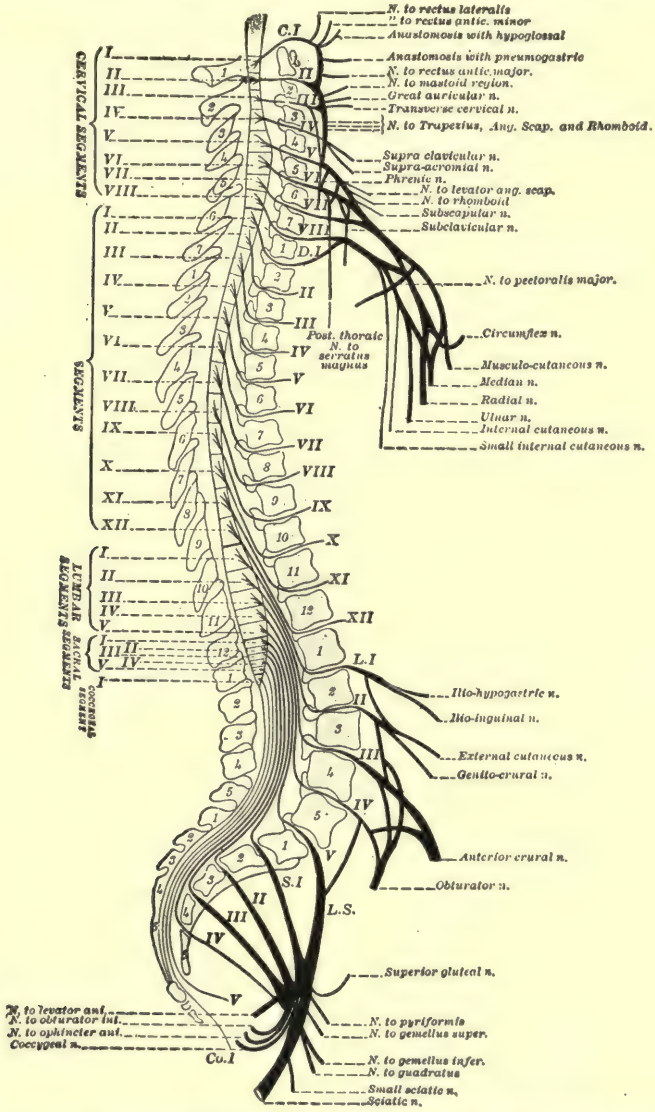

FIG. 252.—RELATION OF THE SEGMENTS OF THE SPINAL CORD AND THEIR NERVE-ROOTS TO THE BODIES AND SPINES OF THE VERTEBRAE. (Déjerine and Thomas.)

sion of the posterior roots at their exit through the intervertebral foramina or of the respective cord-segments. Distribution of pain is difficult of interpretation in this region. The roots are so closely grouped together

that even a small tumor may involve a large number of roots and bring about severe pain in the entire distribution of the lumbosacral plexus. Not infrequently the collection of fluid, sometimes above the tumor, in the form of meningitis serofibrosa or other toxic conditions, may cause transitory pains in the upper root region. We must be on our guard and not allow these dissociated or transitory pains to influence our topographical diagnosis of the lesion, but give consideration only to the highest level of the constant pain. The girdle sensation is usually of value in determining the level of the lesion, since it is caused by irritation of the nerves at the lowest level of the healthy cord, just above the transverse lesion. However, here again there are many eccentricities and this phenomenon cannot be relied upon absolutely.

The motor disturbances, caused by irritation and compression of the motor roots and tracts and the consequent hypertonus and hypotonus of the muscles involved, are of considerable value in determining the height of the lesion, when considered in connection with other localizing signs. We have sufficient data at our command to trace disturbed function of muscle groups back to their respective segments in the cord, whether it be paralysis, spasm, tremor or contracture (Fig. 252).

There is always reflex disturbance in tumors of the spinal cord, the nature of which is diminution or loss at the level involved and exaggeration of reflexes whose arcs are situated below the lesion. It fortunately happens that from the first cervical segment to the lower part of the sacral cord there are distributed so many deep and superficial, as well as sympathetic, reflex arcs that a careful study of reflex disturbances, even unaided by sensory examination, gives a valuable clue to the segment involved.

A correlation of the data derived from these three sources, a study of the sensory, motor and reflex phenomena should lead to a correct topographical diagnosis in the majority of instances. Moreover, symptoms referable to the vertebrae are also of assistance in localization. But in this connection it is important to remember, after locating the affected roots, that the point of exit of the nerve roots from the cord and the level of their respective segments do not coincide with the level of the corresponding vertebra; at certain levels the roots run intraspinally for a considerable distance before making their exit through the intervertebral foramina. This difference is scarcely noticeable in the cervical region, but becomes greater and greater as one progresses down the cord (Fig. 252). The relation of various spinal segments to the vertebrae is one of real practical importance. It is well known that there is a marked discrepancy between the length of the spinal cord and the spinal column. The topographical diagnosis is especially difficult in the region of the lumbar enlargement and the cauda equina, because here the nerve-roots traverse the canal for some distance before making their exit. Muskens has done a very excellent piece of research along these lines, showing the great indi-

TABLE XXIV

Muskens' Table of Individual Variations in the Relations of Spinal Segments to Vertebrae

No.	Psychoses	Age	Sex	C 4	T 1	T 7	T 12
				R. L.	R. L.	R. L.	
I.	Dementia paral.	35 years	female	4–5	2	9–10	Terminal point.
II.	Dementia paral.	38 years	male	5–6 6–7	3–4 4–5	9–10 10–11	Terminal point.
III.	Idiocy	42 years	female	6 5–5	5 5–6	10–11 11	1 cm. above point.
IV.	Dementia paral.	40 years	female	4–5	3	10	1 cm. below point.
V.	Dementia senil.	82 years	male	4–5	3	9	2 cm. above point or L. 2-3.
VI.	Idiocy	42 years	male	4	1–2	9	0.5 cm. above point.
VII.	Dementia secundaria	55 years	male	5–6	4–5	10–11	3 mm. above point.
VIII.	Dementia senil.	82 years	female	5	3–4	8–9	L. 2–3 spinal ganglia are situated free in the vertebral canal.
IX.	Dementia senil.	65 years	female	5–6	2–3 3	8–9 9–10	L. 4.
X.	Idiocy	42 years	female	5–6	4–5	11–12	1 cm. below point.
XI.	?	30 years	female	5	3 2–3	9–10 8–9	1.5 cm. below point.
XII.	Idiocy	45 years	female	5–6	2–3	9	1.5 cm. above point.
XIII.	Dementia senil.	68 years	female	6	3 3–4	9 8–9	5–4.
XIV.	Dementia paral.	43 years	female	5–6 6	4–5 3–4	8	
XV.	Epilepsy	.....	female	4–5 6	3 3–4	9 8–9	2–3.
XVI.	Dementia paral.	45 years	male	5–6	3	8–9 10–11	Terminal point.
XVII.	Dementia paral.	48 years	male	5–6 6–7	3 2–3	6–7	Terminal point.
XVIII.	Dementia paral.	43 years	female	4	4	10–11 11–12	0.5 cm. below point.
XIX.	Stupor	45 years	female	5–6	5–6	7–8	L. 2, L. 3–4 cm. above point.
XX.	Idiotia	25 years	female	4–5	C 8	D 8	L. 3.
XXI.	Hydrocephal.	5 years	male	4–5	1–2 2	9 9–10	1 cm. below point.
XXII.	Syph. hered.	4 years	male	4–5	3 2–3	8 8–9	L. 2–3 terminal point across L. 3–4.

vidual variations, and the possibility that we may have to deal with a "*pre*-fixed" or a "*post*-fixed" cord; that is, with one in which the segments have a relatively high or relatively low position. He chose four fixed vertebral points (C_4, T_1, T_7, T_{12}) and examined the variations in their relation to the subjacent spinal segments at 22 autopsies. The accompanying table (Table XXIV) is a tabulation of his results.

After the level of the lesion has been determined, the question arises as to whether the growth is situated on the anterior or the posterior aspect of the cord, although this is not of much importance, as an exploratory operation involves an inspection of every aspect. Though spinal tumors are prone to develop on the posterior or posterolateral side, there are not a few cases on record in which the growth was situated anteriorly or anterolaterally. We cannot rely absolutely on the presence or absence of pain, for while pain is indicative of involvement of the posterior roots, cases have been reported in which the tumor was situated on the posterior aspect where pain was entirely lacking. On the other hand, muscular atrophy is not always present when the lesion is on the anterior surface, as in a case reported by Allen (Fig. 253). Not infrequently an extramedullary tumor may compress the cord on all sides. Yet again, as is sometimes the case with brain tumors, the side opposite the site of the tumor seems to be involved more seriously than the side on which the tumor is situated. These atypical cases are cited merely as warnings against reliance upon the disturbance of a single cord function, and to emphasize the importance of proper correlation of all available data.

Treatment.—The responsibility of the surgeon toward the patient with a focal lesion of the spinal cord admits of no discussion. Excluding such lesions as tabes dorsalis or poliomyelitis, conditions usually clearly recognized beforehand and presenting no surgical indications, there remains a group of lesions of which tumors constitute a large proportion, in which the signs and symptoms point to a distinctly localized lesion, that is, either driving the patient to distraction through pain or destroying the cord by pressure. There are now and probably always will be a certain number of instances in which a precise statement as to the nature of the lesion, before operation, is impossible; the condition may be one of a group amenable to surgical therapy; it may be one in which surgery can have no remedial effect. Hence resort to exploratory operations in all doubtful cases should be made unhesitatingly, and at an early, not a late, stage. An *exploratory laminectomy* is of itself free from any risks peculiar to the seat of attack; it may even be performed under local anesthesia, if for any reason a general anesthetic be either contra-indicated or undesirable. The time has passed, when the traditional fears of opening and exploring the dural sac should be harbored. The earlier the operation is performed, the better the outlook, not only as to maintenance of life, but recovery of function. The emaciated subject, addicted to

FIG. 253.—SPINAL CORD SHOWING SMALL TUMOR INVOLVING THE GREATER PART OF THE RIGHT ANTERIOR NERVE-ROOT OF THE SIXTH CERVICAL SEGMENT. (Allen.)

morphin, worn out with pain and exhausted by the infections of decubitus or cystitis, is a pathetic figure and not welcomed by the surgeon.

The surgery of spinal cord tumors is more appealing and promising than that of intracranial growths, for the reason that a larger percentage are accessible, a larger percentage can be localized and a larger percentage are operable in the technical sense of the term. These are three very significant distinctions, and at once place the surgery of spinal tumors in a more favorable light. Perhaps the most graphic way of expressing the operability of tumors in general is by the following table, based upon an analysis of the findings in 204 operations:

TABLE XXV

Origin of Tumor		Removed	Partially Removed	Removal Not Attempted	Found at Autopsy	Not Stated	Total
Extramedullary	Intradural	70	4	6	3	..	83
	Extradural	30	2	..	..	..	32
Intramedullary		14	7	7	3	1	32
Caudal		11	5	2	2	..	20
Vertebral	Primary	13	10	2	..	..	25
	Secondary	1	6	2	..	..	9
Not stated		..	1	1	..	1	3
TOTAL		139	35	20	8	2	204

From this table it is readily seen that of 204 operations, the tumor was removed in 139 instances, or 68 per cent, was partially removed in 35, or 17 per cent, and no removal attempted in 20, or only 9 per cent. Comparing this estimate with that of operable tumors of the brain, where the percentage of operable growths is nearer 10 than 20 per cent, the contrast is impressive. Since Horsley removed the first tumor from the cord in 1887, the operation has been repeated with increasing frequency as the hazard has been minimized, and up to the present time we have found on record and tabulated 330 cases.

INDICATIONS FOR OPERATION.—These may be summed up in a few words. The recognition and localization of a lesion by a symptom-complex, which indicates a new growth or even, with certain restrictions, a chronic inflammatory lesion, in a patient whose condition is not prohibitive of any operative undertaking, justifies exploration. The location of the lesion in the upper segments is not a contra-indication, as tumors have been removed

successfully from the level of the axis. Nor is it justifiable to discriminate against a case because the tumor is believed to be intramedullary, for this pre-operative conclusion has not always been borne out by the operative findings, and the course of the intramedullary growth may be favorably influenced by removal or mere decompression. With regard to *pain* as a guide, I would quote the position so well expressed by Bailey:

> The presence or absence of pain is not to be relied on to prove that the condition is intramedullary or extramedullary, any more than it is a means of localizing the growth with respect to the circumference of the cord. We shall have to take the same position in regard to spinal cord tumors as we have taken for years in regard to tabes, that is, that pains may be absent in a disease which is usually highly painful, and that the absence of it in any case presenting other sufficient symptoms does not vitiate the diagnosis. Acceptance of this view is extremely important for the successful handling of these cases, for if we are held back from laminectomy by the single reason that pain is absent, we shall either lose the chance altogether of curing many patients, or shall defer operation so long that, when it finally is done, the injury to the cord is past remedy, and the operation serves no purpose other than a demonstrative one.

Bailey's views as to the value of pain as an indication of extramedullary tumor and its presence in intramedullary involvement only partially coincide with my own. It seems to me that it were well if clinicians would realize that in extramedullary tumor pain is the rational symptom and its absence an exception noted, to be sure, not rarely; also that in intramedullary tumor pain is a possible, though rare, symptom whose physiological explanation is far from settled. The exploratory laminectomy has a very definite and a larger field of application than is usually accorded it. It is the only logical procedure in doubtful cases, and it may prove indispensable to life, should an operable tumor be found; or, according to Finkelnburg, as long as in the progressive course of the disease a meningospinal tumor cannot be excluded, an exploratory operation is advisable, since without an operation the patient is steadily progressing to certain death.

There may be, however, conditions under which the *time of operation* should be postponed or its performance abandoned. Postponement may be advised when syphilis is suspected and vigorous treatment has not been used; but even in cases of certain syphilitic origin, operation should not be deferred in the face of evidence of increasing pressure or continued cord disintegration. In the case of tumors, should evidence of complete destruction of the cord be unquestioned, operation would of course be futile; evidence of multiple tumors or diffuse tumor formation is a positive contra-indication, and in the determination for or against operation, the surgeon must weigh in the balance such conditions as malnutrition, advanced age, pronounced cachexia and the like, any one of which might brand the case as inoperable.

A few commentaries may be made upon the indications for operation as applied to tumors of different origins, that is, the extramedullary and intramedullary, the caudal and the vertebral. Oppenheim, Gowers and Horsley, among others, hold that the majority of intradural tumors are operable, and, according to our tabulated statistics, Table I, the proportion of extramedullary to intramedullary is in the ratio of 20 to 3. Of the *extramedullary tumors,* fibroma, endothelioma and neuroma, tumors with gross characteristics most favorable for complete extirpation, are probably twice as frequent as the less favorable types, of which the glioma is an example. The extramedullary growth is at once recognized as the most favorable of all spinal tumors from the surgical viewpoint.

As for the *intramedullary growths,* it must be acknowledged that most are non-encapsulated and of the soft, infiltrating character. In a series of 36 operations (*vide* Table XVI) one-third or twelve were gliomata. It is scarcely a decade since Bruns made the statement that the successful removal of an intramedullary tumor was out of the question, but surgical experience of the past few years makes revision of this statement necessary. Our search through the literature has disclosed 36 cases of intramedullary tumors in which operation has been performed. There have been a few cases of complete recovery, and a larger number in which functional power has been regained in part. An exploratory laminectomy is indicated, therefore, even when an intramedullary tumor is suspected. Whether one may proceed to remove the growth or must be content with a decompression will be determined by the character and seat of the neoplasm. In considering the time for surgical intervention, the more rapid growth of intramedullary tumors and their more rapid destruction of cord tissue should be taken into account. There is, therefore, less justification for delay in attempts at differentiation, as, for example, between a neoplasm *per se* and a luetic lesion, a very frequent cause of delay, or in attempts at accurate localization, perhaps the next most common cause for procrastination. Both excuses are equally reprehensible, if the grounds for suspicion be well based upon a rapid loss of function. Many intramedullary growths develop most readily in the direction of least resistance upward and downward, and may soon become too diffuse for removal, but small encapsulated tumors are occasionally found in the cord, often enough, indeed, to justify intramedullary exploration. In 1907, the first intramedullary tumor was removed by von Eiselsberg with a brilliant result, and the case was reported by Clairmont at the third Congress of German Neurologists in Vienna.

The patient, a young woman *aet.* 29, had suffered for six months from contractures in both legs, and complete anesthesia to touch and pain sensations to a level five centimeters above the umbilicus. At operation a bluish, oval-shaped tumor about the size of a plum was removed from the cord substance at the level of the sixth thoracic vertebra. It proved to be a neurofibrosarcoma, four centimeters long

and one centimeter wide. Twenty-two months after the operation, the patient was able to walk with only very slight contractures in the legs and sensation was normal.

Since the report of von Eiselsberg's brilliant operation, we find recorded in literature 36 operations for intramedullary growths.

In *caudal tumors* we have perhaps the least promising field, not only because of the technical difficulties in isolating the tumor from the entangling roots, but because of the difficulties in topographical diagnosis, and because the cauda equina is a seat of predilection for multiple tumors. In 30 operations for caudal tumors, 14 were completely removed, 9 were partially removed, in five cases none of the tumor was extirpated, and in two cases there was not sufficient data to determine precisely what was done. Without operation the prognosis is hopeless, so that for purposes of comparison we have a mortality of 100 per cent in the abandoned cases, to 16.66 per cent of recoveries, 33.33 per cent of improvements, 6.6 per cent unimproved and a mortality of 43.3 per cent in the operated cases. Of the 13 deaths, 7 were within one month of the operation, while of the later deaths, 3 patients were improved up to the time of death.

There remain for consideration *tumors of the vertebral bodies* or processes. The operability of the *primary tumor* should not be questioned. The majority of these are either benign, such as the chondromata or osteotomata, or are sarcomata. Upon the site of the growth and its accessibility will depend, to a large measure, the success or failure of operation. Those taking their origin from the arches are readily removed, while those arising within the vertebral bodies are beyond the range of surgical aid. Jourdan and Oeconomos have recently reported a rather interesting case of sarcoma of the posterior arch of the atlas which was successfully and completely removed at operation.

The patient, a man *aet.* 33, had had a tumor in the nape of his neck for nine or ten years. Two months previous to the operation, the tumor had reached the size of an orange and pains had begun to radiate to the head, but spinal tumor symptoms were entirely lacking. At the operation the arch of the atlas was found completely destroyed. The absence of spinal cord symptoms was due, in all probability, to the fact that the spinal canal was not invaded, although the tumor took its origin from the atlas. Its slow evolution, so contrary to the case of most vertebral tumors, the authors explain on the ground that the lesion was probably benign in the beginning and later underwent malignant degeneration.

The *secondary tumors* present a separate and distinct problem. These are all malignant, mostly of the epithelial type, in fact metastatic deposits from primary cancers of the breast, esophagus, thyroid, uterus, stomach and prostate. If surgical intervention be considered, it should be undertaken only with palliative intent, as the radical removal of carcinomata of the vertebrae is inconceivable. Occasions will arise when, for the relief of pain, section of the posterior roots may be deliberately planned, even when before operation the otherwise hopeless nature of the condition is

fully appreciated. That mere decompression is of little benefit might be attributed to the fact that permanent structural changes in the form of a transverse myelitis are already established.

Laminectomy.—The mechanics of removing the laminae for purposes of exploration are described elsewhere.[2] Consideration should be given here to certain problems of laminectomy which concern more particularly the performance of that operation in the search for and removal of tumors. Of foremost consideration is the selection of the site and extent of the exposure, also which and how many laminae should be removed. As to the former, it is a matter of common knowledge to those of experience that the tendency has been to make the exploratory opening too low. When tumors have been overlooked at operation and later discovered at autopsy, they are found almost invariably above the limit of exposure. Therefore, in planning the operation bear in mind that the tumor is often, I might say usually, at a higher level than the symptoms indicate. It is my practice first to select the lowest lamina to be removed, or in other words, to determine upon the lowest point of exploration. This is indicated by the lowest segment or corresponding root represented in the upper limit of the zone of anesthesia. I have never had occasion to enlarge the opening downward in search for a tumor, but always upward. For this reason I do not advocate, as others do, that the middle of the incision should correspond to the preconceived level of the tumor.

The length of the primary incision is a matter of little consequence, as it may later be extended in either direction; usually I begin the incision at the level of one or two spinous processes above the upper limit of the contemplated opening into the canal, and continue it to at least one spinous process below. It should be realized that this advice, though at first sight it gives the impression of limiting one's field of operation downward, in reality cautions one as to the great variation in position possible in a given level of anesthesia. Let us take, for example, a patient presenting anesthesia, the upper level of which is through the umbilicus. Now, allowing the lowest segment represented in the upper limit of this anesthesia to be the tenth thoracic, we might advise the removal of the seventh or eighth thoracic laminae in order to expose the segment in question. But the anesthesia might be caused by posterior root involvement from a tumor of the twelfth thoracic segment destroying these roots on their way to the foramina of exit below the tenth thoracic vertebra. In this case, which is by no means a bizarre possibility, we would have to proceed downward, exploring the tenth thoracic roots from their origin to their exit in order to locate the tumor. Therefore, I say with special emphasis, that the lowest segment or *corresponding root* represented in the upper limit of the zone of anesthesia must be our guide.

[2] For a complete description of the mechanics of laminectomy *vide* Chapter XV.

The relative merits of *bilateral* or *unilateral laminectomy* to my way of thinking, permit of no discussion. A liberal exposure is absolutely essential in the majority of instances, not only for the requisite exploration, but for the successful removal of spinal cord tumors. The spinal cord is much more sensitive to insult than the brain. The brain, in fact, can be manipulated within reasonable limits with impunity, in so far as shock or vasomotor disturbances are concerned. This is probably because of the absence of sensory tracts; on the other hand, the spinal cord, with its sensory roots so intimately related that the slightest traction or displacement of the cord is at once felt by the sensory roots, demands every protection against undue trauma. Chiefly for this reason and because the several aspects of the cord, particularly the anterior aspect, cannot be explored conclusively through a unilateral opening, hemilaminectomy should be unqualifiedly condemned. For reasons already laid down, enough laminae should be removed primarily to permit the necessary manipulation with the infliction of the minimum amount of trauma to the spinal cord and roots. Whether primarily three laminae or more be removed, is a question that will be determined chiefly by the definiteness or indefiniteness of the localizing symptoms. As a general rule, at least three laminae and spinous processes should be primarily removed in every instance in which the tumor is intradural. Naturally, the discovery of an extradural tumor after the removal of one or two laminae precludes the necessity for a larger opening. Even with the removal of three laminae as an established minimum, it is often necessary to remove one or two more at a higher level, although with proper illumination the various aspects of the cord can be inspected at least two centimeters above the level of the opening.

The desirability of completing the cruder work on the laminae before the dura is opened is self-evident. All sources of hemorrhage should be under control, so that once the dura is opened, with proper protection the dural sac may be kept bloodless throughout the exploration. Hence the importance of making the primary exposure liberal, so that once having begun the search for the tumor, it will not be necessary to discontinue it for the purpose of enlarging the bony opening.

One- or Two-Stage Operation.—Whether the operation should be in one or two stages is a matter of individual judgment. The advantages of completing it at one stage admit of no dispute, but conditions may arise at any operation when, in the judgment of the surgeon, the safety of the patient is best conserved by postponing the completion to a second stage. Leaving out of consideration altogether at this time the two-stage operation for intramedullary growths, we look to the pulse and blood pressure, chiefly the latter, as the determining factors for or against the two-stage method. To this end, in our clinic, blood pressure observations are made routinely, and if at any time after the laminectomy has

been completed, the blood pressure should continue to fall until the systolic pressure reaches 90 mm. Hg, I would discontinue the procedure. This, however, so far as our experience goes, is a purely hypothetical situation, as we have never been obliged to resort to the two-stage method in operations for tumors. This opinion is entertained very generally by those who have given their views expression, among whom may be mentioned Horsley, Krause, Borchard, Küttner and von Eiselsberg.

Extradural Tumors.—In the search for tumors it is to be remembered first that the differential diagnosis between extradural and intradural tumors is often not clearly and sharply defined, and secondly, that the intradural or subdural tumor outnumbers the extradural growth by almost 2 to 1. With these two general statements in mind, the search proceeds systematically. After the epidural fat and venous plexus have been gently displaced, and the surface of the dura exposed, a careful inspection is made first of the posterior aspect. If, as may happen, the tumor be more or less pedunculated and free, it is gently elevated, its point of attachment to the dura severed and the tumor removed. When the tumor has a broader attachment to the dura it may be necessary, as in one of my cases, to resect a portion of the dura. The question will arise, should the tumor be adherent to or involve the roots, whether one or more should be sacrificed, or an attempt made to disentangle the roots from the tumor. Whether the roots be conserved or sacrificed must depend altogether upon the character of the growth. If there be any reason to believe the roots distinctly involved, whether anterior, posterior, or both, the roots should be resected with the growth. To sacrifice one, two or three sensory roots at any level of the cord would be a matter of small consequence, but the sacrifice of as many anterior roots from segments supplying the upper or lower extremities, would of necessity be followed by permanent motor curtailment of more or less importance, according to the location and number of the roots.

Before opening the dura a careful search should be made for other possible causes of compression. Extradural probing for tumors either above or below the region explored is of more theoretical than practical value. With more accurate methods of localization and more liberal exposure through larger openings, the possibility of overlooking a spinal tumor has been reduced to a minimum, and if the symptoms of tumor be definitely established and the tumor not exposed, the opening should be enlarged upward by the removal of one or two additional laminae. Rarely will the tumor be situated as many as two laminae above the point indicated by the localizing phenomena. Before opening the dura, the lateral as well as the anterior aspects of the vertebral canal should be inspected, and to accomplish this the cord is gently raised with glass retractors, first to one, and then to the other side, and in doing so the

greatest deference should be paid to the roots, which in all spinal procedures must be handled with the utmost gentleness.

Intradural Extramedullary Tumors.—Failing to find an extradural tumor, the dural sac should be opened in every instance. To discontinue exploration without a subdural search is inexcusable. As clues to the presence of a subdural growth, I look for increase in tension, for the absence of pulsation and for an increase in size of the cord. While in most cases there is an accumulation of fluid above the tumor, accounting not only for the increase in tension, but for the absence of pulsation, there may also be an accumulation of fluid below. The normal cord pulsates synchronously with the action of the heart, and there is a wave of expansion contemporaneous with inspiration. From my own observations at the operating table, I should say the latter is the larger, grosser movement, more readily detected, and the more often present. The former is a finer movement, not always visible to the naked eye, and less reliable. Whenever the fluid content of the dural sac is increased because of the tumor obstruction, or for some less obvious reason pulsation is arrested, the dura on palpation is extremely tense and sometimes the diameter of the dural sac increased. As soon as the sac is punctured, the fluid spurts out as though under great tension, and pulsation returns. These several observations are mentioned in passing, merely as sidelights to the search for the tumor; nothing should interfere with a free dural incision and thorough exploration of the subdural space when up to this point the tumor has not been found.

The incision in the dura should be made with the greatest care, for frequently the arachnoid is closely adherent to the dura, and very occasionally, as in the case of hemangioma reported by Cobb, enormous vessels will be disclosed upon opening the dura. In the latter instance, however, the deeper color of the vessels may be visible through the dura. The findings at the operation in the case described by Cobb were as follows:

> The exposed dura was tense, bulging, and transmitted an unusually dark subdural coloration. . . . Such of the arachnoid membrane as could be identified was more or less adherent to the dura by fine adhesions which readily broke down as the dura was drawn to each side. This exposed an extraordinary tangle of huge pulsating vessels filling the canal (Fig. 254). It was possible in a few places to see the normal coloration of a very flattened spinal cord, through and below the meshwork of vessels. It seemed futile to attempt to ligate any of the vessels, and the dura was therefore left widely open, and the wound closed as usual in layers, without a drain. The patient made a good recovery, but had a very uncomfortable convalescence. Priapism disappeared soon after the operation, but the other symptoms, including spastic paralysis, incontinence and anesthesia, remained unchanged at the end of six months.

In the search for the extramedullary intradural tumor, keep in mind that the majority of tumors are extramedullary, according to our

statistics in the proportion of three to one; that the majority of extramedullary tumors can be readily removed without damage to the cord; that they will be found more often over the lateral or posterior than over the anterior aspects of the cord, approximately in this proportion: anterior 7 per cent, anterolateral 11 per cent, posterior 40 per cent, posterolateral 40 per cent, finally that 65 per cent originate in the thoracic and 30 per cent in the cervical or cervicothoracic territory. With the laminae completely removed, with the dura incised throughout the length of the bony opening, there is no difficulty in detecting the presence of the tumor in the posterior or posterolateral aspect. Occasionally, a thickened or edematous arachnoid, until divided, may obscure the view. Failing to find the tumor at the preliminary inspection, the other segments of the cord surface are systematically scanned for the growth; very gently the cord is retracted, first to one side, then to the other and finally gently elevated. That a small tumor on the anterior aspect may be overlooked even with a liberal opening is regretfully acknowledged in my own experience, fortunately the only instance in which the existence of a tumor, not discovered at operation, has been revealed at autopsy. With this experience in mind the possibility of overlooking an anterior extramedullary tumor is called to the operator's attention.

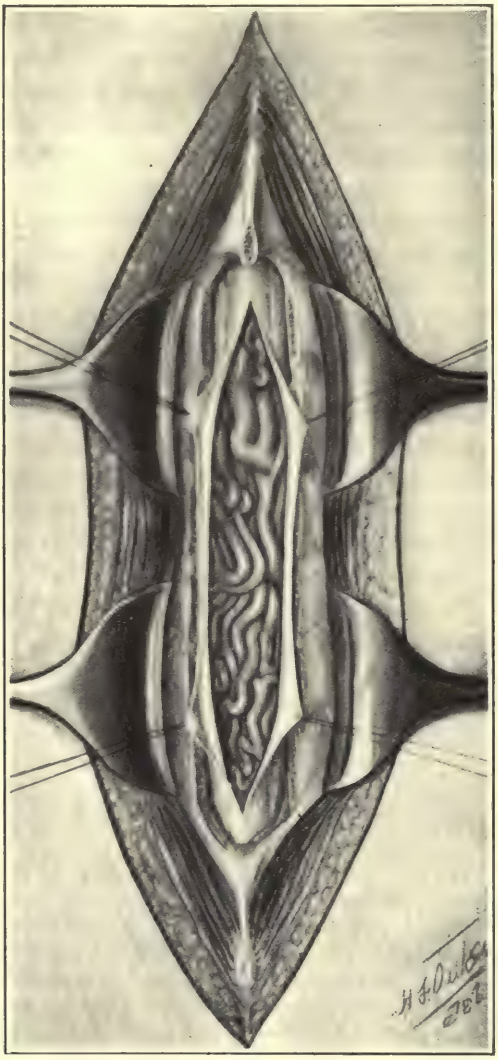

FIG. 254.—DRAWING MADE AT OPERATION, SHOWING INCISED DURA WITH HEMANGIOMA BENEATH. (Cobb.)

Failure to find the growth in the chosen exposure should not conclude

the search. As a matter of routine the segments of the cord above and below are inspected with artificial illumination; a clear view of the cord is obtained as far as the next laminae; this inspection may give a clue to the situation of the growth, but must not be relied upon altogether. Neither do I place reliance upon the almost universal practice of other surgeons of exploring above or below the seat of the opening with probe or sound. I have never been able to detect the existence of a growth in that way, and the risk of damaging roots and of the possible production of hemorrhage by so doing must be taken into consideration. Direct exposure of all cord surfaces to naked eye inspection is the only dependable method and to observe this principle one or more additional laminae must be removed. The tumor found, it should be removed as far as possible unmutilated. I question the propriety of the use of the curet, which to my mind implies a fragmentary and crude method of removing the growth. The final extirpation will be more or less difficult, depending upon whether the tumor is adherent or non-adherent to the dura, whether there is little or much root entanglement, and finally whether the surface attachment is by a broad or thin pedicle. The tumor with a thin pedicle is readily removed; with a broad dural attachment, I remove the adherent portion of the dura with the growth. The disentanglement of the roots requires patience and judgment. In one of my cases in attempting to differentiate between the disarranged roots, I was able to distinguish the anterior from the posterior root by the twitching of the limb when the anterior was touched. To sacrifice roots may be a matter of necessity if the removal of all tissue involved in the growth be held as the criterion of a successful operation. The functional disturbance must not be a consideration when dealing with malignant growths, as the extent of anesthesia or of muscular incapacity is the lesser of two evils. Inasmuch as not one but three posterior roots are represented in each peripheral distribution, two or three posterior roots may be sacrificed without fear of consequences; of the anterior roots, those from thoracic segments may be sacrificed with greater impunity than those of cervical or lumbar origin.

As the space within the vertebral canal has its limitations, extramedullary tumors must trespass on the space occupied by the cord, and so one finds a flattening of the cord or a depression on its surface corresponding to the shape and size of the tumor. But the tumor once removed, complete obliteration of the cavity takes place in a surprisingly short time, just as after the removal of a large blood clot from the cranial cavity the brain soon occupies the space from which it was displaced. Such hemorrhage as there may be after the growth is removed is usually slight and not a troublesome matter, and may be controlled by a tampon saturated with hot water or with a 1-10,000 solution adrenalin chlorid. Excessive heat, however, must not be applied directly to the cord. For

oozing not thus controlled, especially from the cord, I prefer a sliver of muscle tissue. When all is said and done, once the tumor is found the surgeon's greatest anxiety is over; the removal of an extramedullary growth does not present many serious obstacles.

Intramedullary Tumors.—In opening the discussion upon the surgical aspects of intramedullary tumors a few pertinent facts may be mentioned. The intramedullary growth is but one-third as frequent as the extramedullary, it is almost invariably single, not multiple, and does not metastasize. The majority develop in the cervical or thoracic segments and have a predilection for the posterior rather than the other columns of the cord. As to their operability, a distinction must be made between the enucleable, represented by the endothelioma, neurofibroma and fibrosarcoma, and the non-enucleable, the glioma and gliosarcoma. Statistics may vary, of course, with different groups of cases, but in 36 cases in which the lesion was exposed on the operating table and the nature determined, one-third belonged to the non-enucleable type. Preconceived notions as to whether a tumor is intramedullary or extramedullary frequently have to be revised at the operating table, as a differential diagnosis cannot be made with any great degree of certainty. The rule for the preliminary incision and the size and level of the opening does not differ from that generally prescribed for spinal tumors, namely: Select the lowest laminae to be removed, or in other words, determine upon the lowest point of exploration. This is indicated by the lowest segment or corresponding root represented in the upper limit of the zone of anesthesia.

The presence of an intramedullary growth will be suspected by the absence of pulsation, by the accumulation of cerebrospinal fluid above the site of the growth. The pressure of the cerebrospinal fluid as estimated by lumbar puncture below the tumor will be found diminished if the encroachment upon the dural sac be sufficient to cut off completely the subdural space caudad to the growth from that cephalad. The most striking evidence, to be sure, is the augmentation of the cord, which is usually fusiform in shape and quite symmetrical. Inspection may detect some variation in color, if the tumor has reached the surface, and additional information as to the character of the lesion, whether cystic or solid, may be derived by palpation. As Elsberg points out, it is not always easy to distinguish a subpial growth adherent to the cord from an intramedullary tumor that has herniated through the cord periphery.

With these prefatory statements we come to the really vital problem: the method of uncovering and of removing the intramedullary growth. I am taking for granted that *a priori* the intramedullary growth is not of necessity inoperable; and this statement is made with the fullest recognition of the difficulties to be encountered. Reference may be made again to the brilliant outcome of von Eiselsberg's experience in the first

operation for the removal of an intramedullary tumor. The operator should be reminded that the cord and its roots are extremely sensitive to insult and every precaution should be taken to observe here, even more than in extramedullary tumors, the most delicate manipulation. Exploratory incisions in the cord should be made, as Allen has taught us, either with his knife especially devised for the purpose or with a thin, two-edged cataract knife. But where shall the exploratory incision be made? As a matter of convenience and for physiological reasons the incision should be longitudinal and in the median line. In his experiments, Rothmann found that even after resection of both posterior columns in the upper cervical region there was but little functional disturbance, some loss of localization, but none of touch. This observation was confirmed by the experience of Petrén and Fabritius, who found that, if the other tracts be left intact, the posterior columns may be resected without fear of loss of tactile sensation. The incision should be made as near the posterior commissure as possible, and from Allen's work it seems patent that the incision may extend completely through the cord, provided, of course, that in length it be limited to one segment. Halstead, referring to Allen's work, expresses disapproval because in such deep incisions certain decussating fibers would be cut. This criticism would be of moment were the incisions unlimited; but where the incision, as in exploration for tumor, would usually involve but one, rarely more than two segments, the resulting functional disturbance would be relatively too trivial to be regarded as a contra-indication.

Of equal importance with the exploratory cord incision is the completion of the operation in one or two stages. This must be considered from the standpoint of safety, as for all operations upon the cerebrospinal system, as well as in its relation to the removal of spinal tumors by the extrusion method, a two-stage process. Disregarding the latter for a moment, I believe the burden of proof always rests with those who recommend routinely a two-stage rather than a one-stage operation upon the cerebrospinal system, unless there be some positive indications for postponing the final stage, such as in a falling blood pressure.

The universal adoption of the extrusion method in the attempted removal of medullary tumors cannot be endorsed until it has been more widely tested. To my way of thinking, some distinction must be made between the definitely encapsulated, non-infiltrating, and the definitely non-encapsulated, infiltrating growth. Whatever may be said of the influence of decompression, the operability of a soft, infiltrating glioma either of brain or cord must be questioned. The removal of as much of the gliomatous tumor as might be found extruded from the cord at a second sitting, probably adds nothing to the risk of the operation, but on the other hand, adds nothing to the span of life; whereas, a decompression will give as much transitory relief; moreover, partial fragmentary attempts

at removal of infiltrating growths of the brain or cord have a stimulating rather than a retarding influence upon the growth. To be sure, there may be cases difficult of diagnosis by the naked eye at the time of operation; but if the tumor appear to be a glioma, I question the propriety of removal either in one or two stages. This is said with due regard for the reports from the clinics of Potel and Veaudeau and of Elsberg, and for their original contributions, but so far as may be determined from the records of gliomatous tumors there have been no permanent recoveries,

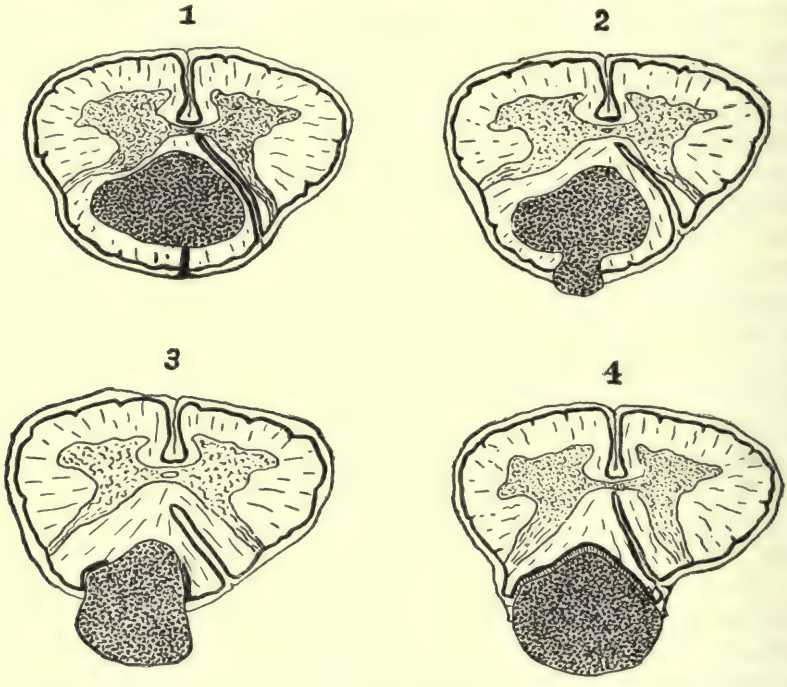

FIG. 255.—DIAGRAM OF THE EXTRUSION OF AN INTRAMEDULLARY TUMOR AFTER THE INCISION INTO THE CORD HAS BEEN MADE. (Elsberg.)

and the longest survival after operation has been two years (Hertzler's case reported by Robinson). When Elsberg published his experience with the extrusion method the longest period of survival after removal of a glioma was eight months.

The question of a one- or two-stage operation in intramedullary tumors has been opened for discussion by Elsberg's proposal to allow the growth to extrude itself from the cord through the exploratory incision. In favor of this two-stage method, it is claimed that if an incision be made through the cord down to the tumor there is enough intramedullary pressure to extrude the growth and that nature can accomplish the removal of the tumor from the cord with far less injury to the cord structures than the most careful manipulations of the surgeon. An incision one centimeter

long is made through the posterior median column a few millimeters outside the posterior median fissure, just where the tumor appears nearest the surface. Upon the completion of this step no further attempt is made to remove the growth; the muscles, fascia and skin are closed and the wound reopened a week later. If at this time the tumor have freed itself from the cord, it is removed (Fig. 255). If at the second operation the tumor be found still closely attached to the cord tissue, Elsberg advises against its removal, because in one instance an attempt to remove an intramedullary fibrolipoma when there was still a slight attachment to the cord was followed by symptoms of a transverse lesion. In several later cases in which he allowed the tumor to remain, leaving the dura open, practically a decompression operation, the condition of the patients improved so much that a later operation seemed unjustifiable. Potel and Veaudeau followed this "extrusion" technic in a case of gliosarcoma between the fourth and fifth cervical segments. One week after the first stage, the tumor mass, 5 x 2 x 2 cm., had been expelled from the cord. The immediate convalescence was uneventful and eight months later the patient was able to walk and was relieved of pain.

Final acceptation of this method of extrusion as a universal practice must depend upon the ultimate results of a reasonably large series of cases. Upon general principles it would seem wiser not to be too arbitrary in our rulings, but to be guided by the character of the growth and its position in the cord. Other things being equal, we should aim to complete the operation in one, rather than two, stages.

Caudal Tumors.—Tumors of the cauda equina present perhaps the most difficult problems, both technical and otherwise. Because of the distance traversed by the roots within the dural sac, exact localization is often impossible. Caudal tumors are preponderantly malignant, and so entangled in the roots as to hamper attempts at removal without injury. In a series of twenty-four operated cases, Klieneberger observed that of those which came to autopsy but 15 per cent proved capable of complete extirpation. The depth of the wound and the free oozing are also disturbing factors; the low situation of the wound exposes it to contamination with urine or feces, and it would seem as though patients with caudal tumors were most prone to develop decubitus. Recognizing the unquestionable difficulties in the removal of caudal tumors it should be borne in mind that there are a number of cases with symptoms of caudal lesion in which the tumor has been found at operation to be extradural, so that there was no necessity of opening the dura. This, together with the fact that the effect of decompression is quite striking, is offered by way of encouragement to those who might be disposed to discountenance operative intervention in all cases.

To return to the question of localization in tumors of the cauda equina and conus medullaris, the area to be considered includes ten inter-

vertebral foramina, from the first lumbar to the fifth sacral. The distance traversed by a single root from its origin to the point of exit from the dural sac may be, as by the first sacral, fourteen centimeters. In the differential diagnosis and in the localization, confusion arises because the same functional disturbance may result from pressure upon the spinal segment as from that upon the corresponding pair of roots some distance from their segmental origin. In one of Schultze's cases, the symptoms were confined to the distribution of the sciatic nerve and lower roots of the cord. The upper lumbar roots, because of their lateral position at this level, were not involved. The lesion in this case was not one of the cauda equina at or below the fifth lumbar vertebra but of the lower part of the lumbar swelling of the cord opposite the last thoracic and first lumbar vertebra. While Schultze's case was a fracture of the spine and not a tumor, it illustrates the possibility of error in the localization. In a case upon which I operated for Spiller, the tumor was readily exposed after removal of the arches of the second, third and fourth lumbar vertebrae, but the surgeon must be prepared for a more extensive opening when the tumor is not so readily localized. In a case reported by Collins and Elsberg, the operation began by removal of the spinous processes and laminae of the third, fourth and fifth lumbar vertebrae, but it was found necessary to enlarge the opening in order to include the processes of the first and second lumbar and eleventh and twelfth thoracic vertebrae before the tumor could be removed. The growth, an endothelial sarcoma, extended from the conus upward over the lumbosacral cord and measured fourteen centimeters in length.

In order to avoid contamination of the wound, in cases of incontinence of urine, a permanent catheter should be employed at least until the wound has healed. The involvement by the growth of the sacral roots, innervating the bladder, accounts for a preëxisting cystitis and often a pyelitis. The incidental trauma to these roots while isolating the growth may leave the bladder incapable of evacuating itself for a time after the operation. In these several complications and in the endeavor to protect the wound, we have positive indications for permanent catheterization in the immediate convalescence.

Vertebral Tumors.—The surgery of primary and that of secondary vertebral growths demand separate consideration. It is a reasonable estimate that eighty out of one hundred secondary growths are metastatic carcinomata and are utterly inoperable in the technical sense of the word. In spite of this, however, the agonizing pain to which the patient is subject is so appealing that I have been persuaded to resort to a palliative operation. Such an operation involves not only relief of pressure by a laminectomy, but amelioration of pain through resection of the posterior roots, and further consideration of this will be reserved for the chapter on the spinal roots. What has been said of carcinomata applies with almost

equal force to sarcomata with perhaps these differences: (1) the latter are primary growths, (2) at the outset the utterly hopeless aspect of the case is not known, and (3) some types of sarcomata are not so malignant as carcinomata. I have in mind an experience of Helling whose patient was well and without recurrence three years after the removal of an osteofibrosarcoma. The tumor arose from the arch of the fourth lumbar vertebra, compressing the cauda equina, and necessitated the removal of a portion of the dura with the tumor. Taking their origin, as most of them do, from the arches or laminae, these tumors are readily accessible and, while recurrence is the rule rather than the exception, the possibility of affording at least temporary relief from the torturing pain is of itself a demand for operative intervention.

Among the *primary benign tumors* of the vertebral column are to be found the enchondromata, osteomata and fibromata in various combinations. Our suspicions as to the presence of a growth of vertebral origin are aroused chiefly by its shadow in the roentgenogram, by the presence of localized tenderness and, according to Oppenheim, by the dullness of the note in percussion, but of these three the roentgenogram offers the most conclusive evidence. The dull percussion note, as described by Oppenheim, is a very uncertain sign, which one may frequently try to elicit without success. An unusually clear roentgenogram of a tumor was obtained in a case under the care of Dr. Dean Lewis, a case which, because of the positive roentgenogram and the unusual nature of the tumor, a fibroma, is of sufficient importance to be mentioned in this connection.

Fibroma taking its origin from the periosteum of the vertebra in the lower thoracic region. Extraordinary degree of improvement and partial disappearance of the tumor following a decompressive laminectomy.

The patient, a woman, *aet.* 25, was admitted to Presbyterian Hospital, Chicago, Sept. 21, 1913, under the care of Dr. Dean Lewis. Her family and past medical history were negative. In March, 1912, she began to suffer pain in the left lumbar region and tired feeling in the lower extremities. The lumbar pain lasted for two or three months. By October, 1912, she was unable to walk and the preceding August she lost control of her sphincters, but by February, 1913, had regained control of the rectum and partial control of the bladder.

Physical Examination.—There was a spastic paralysis of both lower limbs with patellar and ankle clonus and bilateral Babinski reflex. The upper abdominal reflexes were present on both sides, but the lower abdominal reflexes were absent on the left and weak on the right. Examination for sensory disturbance demonstrated a complete loss of tactile and a partial loss of pain and temperature sense in all parts of the lower extremities and a partial loss of all forms of sensation in the lower part of the abdomen below a horizontal line eight centimeters above the pubis.

The Wassermann test of the blood and spinal fluid was negative. The Nonne-Apelt globulin reaction was very strong, and the Lange colloidal gold test gave a marked reaction at much higher dilution than is seen in syphilitic lesions. The x-ray examination showed a definite mass along the left side of the spine in the lower thoracic region, most marked at the tenth thoracic vertebra (Fig. 256).

Laminectomy, October 1, 1913. The arches of the lower five thoracic vertebrae being removed, a soft tumor was found intimately connected with the bone and outside the dura. This growth caused a flattening of the cord, particularly at the tenth thoracic vertebra. The capsule of the tumor was incised and stitched to the lumbar muscles in the hope that the mass would grow outward rather than into the spinal canal, thereby relieving pressure on the cord. No effort was made to remove the tumor on account of its size and probable malignant nature. The histological examination of a small piece of the growth removed at this time showed

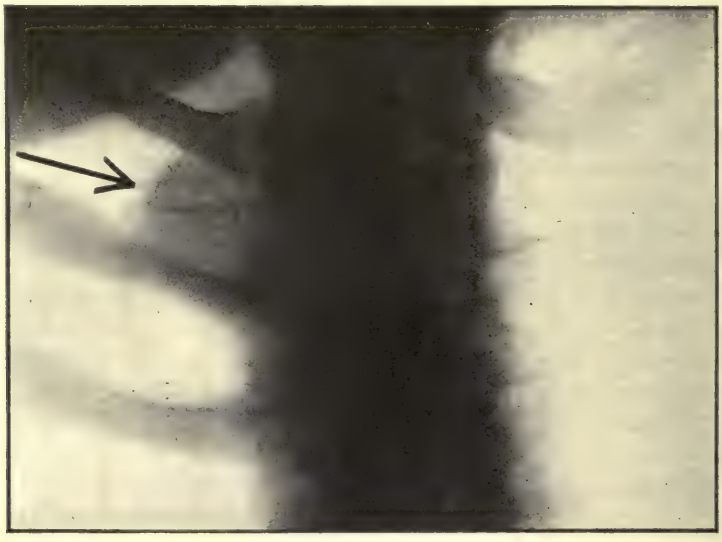

FIG. 256.—ROENTGENOGRAM OF FIBROMA OF THE VERTEBRAL COLUMN, THE DIAGNOSIS BEING CONFIRMED AT OPERATION. (Dean Lewis.)

fibrous tissue rich in spindle-shaped cells. It was classed as a fibroma rather than as sarcoma.

Contrary to expectations, the patient improved very rapidly. The next day she began to move the toes and sixteen days after the operation she was able to take a few steps when supported by two nurses. By this time the sphincter disturbance had disappeared and cutaneous sensation was normal, though the sense of passive movement was still impaired. She was discharged from the hospital on November 12, 1913.

When next seen, September 1, 1914, she complained only of a little stiffness and uncertainty when walking and occasional cramps in the muscles of the right thigh. There was no sphincter disturbance. The knee and ankle jerks were still exaggerated and Babinski reflex was present on both sides. A soft, non-adherent mass could be felt along the lower third of the laminectomy scar.

We have never had occasion to operate for a benign tumor of the vertebrae; as a matter of fact we could find on record, all told, not more than fifteen operative cases, but from the experience of others, there are no points in the technic that require special emphasis. As a rule, the dural sac is not opened and the risk of operation incidental to escape

of cerebrospinal fluid and infection is thus avoided. Occasionally adherence of the tumor to the dura mater may require a very limited resection, or may cause a tear in the dura during removal of the growth, as in one of Krause's cases. The patient, a woman twenty-two years of age, five years before her admission began to suffer from weakness and paresthesia in the lower extremities, particularly the left. Later she experienced pains in the back and in the hypochondrium, and the lower extremities gradually became rigid with marked ankle clonus on the left. The Babinski, Oppenheim and Bechterew-Mendel signs were present on both sides; the tendon reflexes were somewhat exaggerated in the upper extremities, especially the left. Tactile, pain and temperature sensations were reduced in the right lower extremity, the zone of tactile anesthesia extending up the trunk to the lower border of the second rib. The spinous processes of the third and fourth thoracic vertebrae were very sensitive, and the roentgenogram seemed to show a slight change. Oppenheim believed the tumor was at the level of the seventh cervical vertebra, the slight disturbances in the upper extremity being due to a collection of fluid at the level of the third thoracic vertebra. Accordingly, Krause removed the arches of the sixth cervical to the second thoracic vertebrae, and a cartilaginous mass was revealed on the left side of the dura, originating in the body of the seventh cervical vertebra and extending to the upper border of the sixth. The tumor was closely adherent to the dura, from which it was separated and bluntly removed. Nevertheless, a tear two centimeters long was made in the dura at the level of the seventh cervical vertebra. The tumor, which proved to be an enchondroma, was about the size of a walnut and had compressed the cord to a ribbon-like thinness.

Of *inoperable tumors of the vertebrae,* be they sarcoma or carcinoma, the treatment should include the administration of *Coley's fluid* and *roentgenotherapy.* There is no doubt that a certain percentage of cases of sarcoma will disappear under the influence of Coley's fluid; just what the percentage of recoveries is, is a matter of little moment; granted the percentage is small, we are charged with the obligation to give the patient the benefit of the doubt. The following case came under my observation:

An inoperable sarcoma of the seventh thoracic vertebra with complete loss of motion and sensation below the umbilicus. A decompressive laminectomy and a course of Coley's fluid, followed by restoration of sensation and voluntary movement. With the aid of braces the patient became ambulant.

The patient, a male, *aet.* 56 (File No. 36353), was admitted to my service at the University Hospital, March 2, 1917, with the following history: About a year ago he began to complain of pain in the left hip, pain being aggravated by flexion of the thigh on the abdomen. At that time he walked with a slight limp and occasionally took to his bed. An examination, April 26, 1916, revealed diminution

of the biceps and triceps tendon reflexes, partial loss of the right patellar and complete loss of the left patellar reflex. There were no sensory disturbances.

November 17, 1916, he had complained of weakness in the lower extremities and pain in the back, referred to the area between the seventh and tenth ribs and aggravated by exertion. There were no rectal or vesical symptoms. Tactile sensation was normal, but heat and pain sensations slightly obtunded below the knees. The patellar tendon reflexes were diminished, ankle clonus was present on the left side.

FIG. 257.—CASE OF INOPERABLE SARCOMA OF THE SEVENTH THORACIC VERTEBRAE, WITH COMPLETE LOSS OF MOTION BELOW THE UMBILICUS.

Showing restoration of function seven and a half months after a decompressive laminectomy, followed by a course of Coley's fluid.

Feb. 24, 1917: There was loss of pain and tactile sensation below the level of the umbilicus and voluntary movements of the lower extremities were lost. The reflex movements were exaggerated. The Wassermann reaction was negative. Provisional diagnosis was tumor of the cord between the ninth and tenth thoracic segments.

Laminectomy, March 3, 1917: Paravertebral anesthesia. Removal of the laminae of the fifth, sixth and seventh thoracic vertebrae revealed a tumor involving the seventh vertebra and the underlying dura. The tumor was too extensive to warrant removal and further steps were discontinued and the wound closed.

Pathological Diagnosis: Spindle-cell sarcoma.

Immediately after the operation the administration of Coley's fluid by Dr. Coley's method was begun and continued for six months.

June 11, 1917: About three months after the operation the patient had recovered sensation almost completely in the right and, to a considerable degree, in the left lower extremity and voluntary movement in the left but not in the right lower extremity. In the latter, movements were considerably restricted by spasticity.

Rhizotomy, June 18, 1917: Spinal anesthesia. For the relief of the right-sided spasticity the roots of the first and second lumbar and the second sacral segments were ligated and divided. Although only three roots were cut the spasticity was diminished sufficiently to restore voluntary movement to the right leg.

October 29, 1917: Seven and a half months after the operation sensation had returned from the level of the umbilicus down, as had also voluntary movement. Braces had been provided and with assistance the patient was able to walk. An x-ray examination failed to detect any evidence of the growth. This finding, together with the return of sensation and of voluntary movement, justified the assumption that not only had the tumor not increased in size, but had undergone retrograde changes—at least to a very considerable extent.

Through the courtesy of Dr. W. B. Coley I have had the opportunity of examining the clinical records of thirteen cases, the information from which I have arranged in tabular form (*vide* Table XXVI).

In this series there are seven cases reported well from one to seventeen years after the treatment was begun; four of these seven were free from recurrence over four years or more. Of the remaining six, one had a recurrence after two years, but was well at the time of the report after four years, in one there was no improvement, in one continued improvement for one year up to the time of the report and two died. The following is taken from Dr. Coley's records and is an illustration of what may be accomplished by the use of the fluid even in advanced cases.

The patient, a male, *aet.* 21, entered the Montefiore Home for Incurables in April, 1901, at which time a large swelling was noticed in the lower thoracic region; the patient was unable to walk, but there was no paralysis of the leg. About six months after, a tumor was noticed on either side of the spinous processes of the lower thoracic and upper lumbar regions, which gradually increased in size until February 18, 1902, when it was exceedingly large and involved all the vertebrae from the eighth thoracic to the third lumbar; the muscles of the thigh were markedly atrophied and there was great general emaciation, total paralysis of bladder and rectum, and the patient was unable to turn over in bed; he had lost fifty pounds in weight. When Dr. Coley saw the patient his condition was regarded as hopeless; the diagnosis had been confirmed by an exploratory operation and by microscopical examination. The toxins were begun with little hope of giving more than temporary relief, the treatment being carried out under Dr. Coley's direction. The injections were made into the buttocks and pushed to the point of producing a moderate reaction with a temperature of 103° or 104° F. Improvement was almost immediately noticed and steadily continued. By the end of September, 1902, the patient's general condition had markedly improved, and the tumor had considerably decreased in size. The total paralysis was replaced by fair motive power and ability to walk; the reflexes returned to their normal condition, and the area of sensory disturbances had diminished in extent and intensity. There was still some retention of urine and some constipation. A plaster jacket was applied, which the patient wore for a number of months. Improvement continued until early in 1903, when he had entirely recovered and the plaster jacket was discarded. He resumed his regular occupation, and twelve years later was in good health. A letter received from the patient, August 10, 1912, reads as follows:

"I know you would be surprised to see my improved condition. The last two and a half years I am working every day, and physical hard work, but I am feeling strong and my general condition is better than I ever dared to expect. I weigh 145 lbs.; the muscular development of my chest, arms, shoulders and stomach is wonderful to what it was even three years after my sickness, when I weighed 95 lbs. My boys, one six and one four, are in the best of health."

The patient was shown before the New York Surgical Society in May, 1914, in perfect condition. He was also shown at the clinical conference of the Memorial Hospital in 1916 in the best of health.

Another case of inoperable tumor of the spine treated by Coley's fluid is the following (Harmer):

TABLE XXVI

CASES OF SARCOMA OF THE VERTEBRAE TREATED WITH COLEY'S TOXINS (ERYSIPELAS AND BACILLUS PRODIGIOSUS)

Name	No.	Age	Vertebra	Type of Sarcoma	Pressure Symptoms			Result	Influence on Symptoms	
					Motor	Sensory	Reflex		Motor	Sensory
Coley	I	56	$T_{9, 10, 11}$	Spindle-celled	—	—	—	Well 8 years		
Harmer (Boston)	II	16	T_{10}	Giant-celled	+	+	+	Well Feb., 1917, 5 years	—	—
Coley (Vrodemberg)	III	adult	Sacrum	Giant-celled				Well 5 years		
Coley	IV	38	Sacrum	Clinical diagnosis only	+	+	+	Well 17 years	Recovered muscular power	Pain ceased.
Coley	V	21	T_5 to L_3	Round-celled huge tumor	+	+	+	Well 12 years	Complete recovery	Complete recovery
Coley	VI	2	Cervical	Fibrosarcoma	+	+	+	Well 5 years, Nov., 1917	+	Had cerebral tumor also
Coley	VII	16	$C_{3, 4, 5}$	Clinical and x-ray diag.	+	+	+	Well 6 years		
Coley	VIII	35	Sacrum and coccyx	Round-celled	+			Disappeared; recurred in 2 years, again disappeared. Well at present 4 years later		
Coley	IX	5	Thoracico-lumbar		—	+	—	No improvement; death followed operation by another surgeon		
Coley	X	42	T_6 to T_{10}	?	+	+	+	Death 9 months from beginning of trouble		
Rakestraw	XI	48	L_2	Mixed-celled	+	+	+	Continued improvement 1 year	+	+
Coley	XII	36	Sacrum	?				Improvement. Treatment discontinued; death		
Coley	XIII	20	Lumbar	Giant-celled		+		Exploratory operation followed by toxins. Still under treatment, March, 1917		

A boy, *aet.* 16, was admitted to the Massachusetts General Hospital on June 10, 1912. Three months before he had sustained an injury to the spine and shortly after this a tumor appeared in the lower thoracic region, associated with pain and tenderness. There was a double ankle clonus and Oppenheim reflexes with a disappearance of tactile and pain sense over the right anterior crural distribution. The region of the tumor was exposed, and a specimen removed for microscopical examination proved to be a mixed cell sarcoma. Treatment with Coley's fluid was inaugurated, and in the course of time the tumor began to slough and eventually entirely disappeared. At the last report, which was four years and one month after the toxins were discontinued or nearly five years after the treatment was inaugurated, the patient was entirely well. The tumor had entirely disappeared and there were no objective or subjective disturbances.

In inoperable tumors of the spinal cord or vertebral column, as has already been indicated, pain may be relieved and the condition ameliorated by a decompressive laminectomy with or without division of the posterior roots. One is tempted, however, and more particularly when pain is unbearable, to try the effects of x-ray and radium therapy. To be sure, if the tumor be a carcinoma, the possibility of relief, even though temporary in character, either from the roentgen ray or from radium, is, in the light of our present knowledge, practically *nil.* However, many of the tumors both of the vertebra and the cord belong to the group of sarcoma, and it is a well recognized fact that roentgenotherapy and radium therapy have produced some striking results upon the growth of these tumors. It is, therefore, incumbent upon the surgeon, in the presence of an inoperable growth, to resort to the use of one or the other of these agencies, the selection to be left to the judgment of the roentgenologist. In two cases under my care, Dr. H. K. Pancoast has introduced tubes of radium directly into an inoperable sarcoma of the vertebrae. The effect of this treatment was rapid disintegration and sloughing of the tumor, which was fragmentarily discharged through an open wound. The extensive sloughing which takes place after the employment of radium in large doses might be said to be an objectionable feature, although, of course, many discomforts may be tolerated in the presence of so serious a situation. In the cases above referred to, it happened that the tumors were so extensive that recovery seemed to be beyond the range of possibility, and, while a considerable proportion of the tumors were destroyed, the patients succumbed to metastases to the internal organs.

We have on a number of occasions employed *radium energy* in the treatment of tumors of the brain, but the first application of radium to an inoperable tumor of the cord is to be accredited to Clarke and Lansdowne, who six weeks after an exploratory laminectomy, at which was found an intramedullary growth, reopened the wound and applied 50 mg. of radium in the spinal canal over the tumor. The radium was allowed to remain *in situ* for twenty-two hours. At that time the patient was unable to stand or walk; there was considerable loss of sensation with

retention of urine. Six weeks afterward the patient had recovered sufficient power to be able to sit up in a chair for some hours, to stand unsupported for a few moments and to take a few steps without support. There was also very manifest improvement in the sensory disturbances. In a word, the improvement seemed to the observers greater than that which might have been attributed alone to the effect of a decompressive laminectomy. Unfortunately, retention of urine persisted, cystitis developed and the patient died a few weeks later, probably as the result of an ascending pyelonephritis.

Prognosis.—In reviewing the case histories of tumors of the spine and spinal cord, let us bear in mind that because of the unyielding nature of the spinal canal, the natural growth of a tumor will so compress the cord that, if unrelieved, the outcome must be inevitably fatal. The utterly hopeless outlook of all cases of spinal tumor must not be overlooked. Furthermore, the degree of recovery will depend upon the amount of damage already inflicted upon the cord. The complete removal of even a benign growth will not restore power of limb to the paraplegic if the process of degeneration in the cord be already well advanced. Compared with operations for the removal of tumors of the brain, the status of surgical therapy in spinal cord tumors warrants a more encouraging prognosis as regards not only the immediate but also the terminal results. In forecasting the possible results of operation, the recuperative power of the cord should be considered, and prior to the operation it is not always possible to say whether the loss of function be from compression *per se* or from a pressure myelitis.

Restoration of function is not to be looked for immediately, and the time elapsing between removal of the growth and the first sign of improvement is very variable. Not infrequently there is a relapse at the end of the first or second week, and the maximum of improvement occasionally seen in six months or a year may not be witnessed until at least two years have elapsed. In one of von Eiselsberg's cases in which he removed an intramedullary tumor, eighteen months elapsed before the functional disturbances in the extremities and the bladder began to disappear. Both immediate and final results have a direct relation to the nature, extent and duration of damage to the cord. After long-standing compression, restoration of function, especially motor, will of necessity be slow. When both sensory and motor disturbances are present, the sensory disturbance will be relieved before the motor in most instances, and of the impaired muscular power those muscles first regain function which were the last to be involved and *vice versa*. Not infrequently some spasticity of the affected limbs may continue for years, perhaps may never altogether disappear, according to the degree of degeneration in the pyramidal tracts. Because of this degeneration in the several columns of the cord, an inevitable sequence to pressure or infiltration unre-

lieved, the importance of an early diagnosis is emphasized. Early diagnosis and immediate recourse to operation are the causes chiefly responsible for the lowered mortality rate and the more promising end results of modern surgery. The delay in operation incident to speculative inquiries as to the precise nature of the lesion or its exact seat is an altogether too common practice. The patient's restlessness is appeased somewhat by the thought that relief may follow interminable courses of potassium iodid and mercury, a so-called expectant course of treatment with which the physician consoles himself and his conscience when he is unable to make a diagnosis and is waiting for an inspiration. With the information now in our possession we are able to determine in at least two out of three cases the exact level of the space-restricting process, be that what it may, and in a larger percentage are we able to exclude general systemic diseases in which surgery would be of no avail. Whenever there are motor or sensory disturbances of unknown origin, it should be remembered that we can never entirely eliminate the possibility of spinal tumor.

The majority of deaths following in the immediate wake of the operation are due to shock and later, in order of frequency, to meningitis, pneumonia, pyelitis, decubitus and to the extension of the disease in irremovable growths. Often the patient is so debilitated by infection and pain at the time of operation that he is unable to withstand the insult of an operation conducted in the most efficient manner and under the most favorable auspices. Therefore, wholesale criticism of the mortality rate either from a single clinic or a group of clinics is unwarranted without full knowledge and regard for the condition of the patient and many other factors, such as the seat of the growth, its origin and character.

In general terms we know that (1) regionally speaking the most favorable prognosis may be given in tumors of the thoracic segments as compared with the cervical, lumbar or cauda equina; (2) that with relation to their origin the most favorable are those which arise in the meninges, and the least favorable those of vertebral origin; (3) that the most enduring results follow the removal of benign growths, next in order of frequency, endotheliomata, and lastly carcinomata and gliomata; (4) that the prognosis is much more favorable for patients under twenty years of age; and (5) that the results seem to be practically uninfluenced by sex.

If we reduce these general statements to figures gathered from the records of 330 operative cases, we find the mortality 53.7 per cent in the lumbar region, 42.4 per cent in the cervical and 41.8 per cent in the thoracic (Table XXVII).

Turning to the effect of the origin of the growth upon prognosis, statistics collected from all sources show that the mortality is 62.0 per cent for tumors of vertebral origin, 44.4 per cent for those arising within the cord itself, and only 34.2 per cent for tumors of meningeal origin, includ-

TABLE XXVII

PROGNOSIS ACCORDING TO LOCATION

Location	Recovery	Greatly Improved	Slightly Improved	Unimproved	Death	Not Stated	Total
Cervical	10	17	12	2	31	1	73
Cervicothoracic	3	2	1	..	2	..	8
Thoracic	37	30	17	13	72	3	172
Thoracicolumbar	..	..	2	..	2	..	4
Lumbar	9	13	5	4	36	..	67
Not stated	1	2	1	..	2	..	6
TOTAL	60	64	38	19	145	4	330

ing both intradural and extradural growths (Table XXVIII). That the mortality rate should be so much higher for vertebral and medullary tumors than for meningeal is to be attributed principally to the predominance of malignancy in the former groups.

TABLE XXVIII

PROGNOSIS AS TO ORIGIN

Origin	Recovered	Greatly Improved	Slightly Improved	Unimproved	Death	Not Stated	Total
Extramedullary:							
Intradural	25	23	11	4	34	..	97
Extradural	7	14	13	3	18	..	55
Intramedullary	3	6	5	4	16	2	36
Roots and Cauda	5	8	2	2	13	..	30
Vertebral:							
Primary	6	8	3	2	26	..	45
Secondary	..	..	2	1	10	..	13
Not stated	14	5	3	3	27	2	54
TOTAL	60	64	39	19	144	4	330

Based upon the character of the growth, the influence upon mortality is as follows: Carcinomata 100 per cent, gliomata 64.7 per cent, sarcomata 47.7 per cent, endotheliomata 36.0 per cent and benign growths 35.2 per cent (Table XXIX).

Separate consideration might be given to the sarcomata which in many instances, though belonging to the malignant group, do not in this region exhibit the same tendency to recurrence as elsewhere. Quoting

TABLE XXIX

PROGNOSIS ACCORDING TO PATHOLOGICAL DIAGNOSIS

Pathological Diagnosis	Recovered	Greatly Improved	Slightly Improved	Unimproved	Death	Not Stated	Total
Fibroblastoma:							
Fibroma	9	8	2	1	6	..	26
Fibro-adenoma	1	..	..	..	..	..	1
Fibro-endothelioma	1	1	1	..	..	..	3
Fibromyoma	..	1	..	..	..	..	1
Fibromyxoma	2	1	..	..	1	..	4
Fibromyxomosarcoma	..	1	1	..	..	..	2
Fibrosarcoma	5	7	3	1	13	..	29
Myxoblastoma:							
Myxoma	1	..	..	1	1	..	3
Myxolipoma	1	..	..	..	..	..	1
Myxosarcoma	..	..	1	..	..	..	1
Chondroblastoma:							
Enchondroma	2	..	..	..	4	..	6
Chondrosarcoma	..	1	..	..	1	..	2
Osteoblastoma:							
Osteoma	..	1	1	..	2	..	4
Osteofibrosarcoma	1	..	..	..	..	..	1
Lipoblastoma:							
Lipoma	..	2	1	..	1	..	4
Endothelioblastoma:							
(a) Hemangio-endothelioblastoma:							
Angioma	..	2	..	..	2	..	4
Angiofibrosarcoma	..	1	..	..	..	..	1
Angiolipoma	..	1	1	..	..	..	2
Angiosarcoma	..	..	..	..	4	..	4
(b) Lymphangio-endothelioblastoma:							
Lymphangioma	..	1	..	..	..	..	1
(c) Dural endothelioblastoma:							
Dural endothelioma	5	9	1	1	9	..	25
Lymphoblastoma:							
Lymphosarcoma	..	1	..	..	1	..	2
Myeloblastoma:							
Myeloma	..	1	1	..	1	..	3
Melanoblastoma:							
Melanoma	..	..	..	..	3	..	3

Pathological Diagnosis	Recovered	Greatly Improved	Slightly Improved	Unimproved	Death	Not Stated	Total
Glioblastoma:							
Glioma	2	..	2	2	11	..	17
Gliosarcoma	..	1	..	..	3	..	4
Neuroblastoma:							
Neurofibroma	1	1	..	..	4	..	6
Neurofibro-angioma	..	..	..	..	1	..	1
Neurofibroglioma	1	..	..	..	..	..	1
Neurofibrosarcoma	1	..	..	..	..	..	1
Epithelioblastoma:							
Adenoma	..	..	1	1	1	..	3
Carcinoma	..	..	..	..	10	..	10
Embryoblastoma:							
Teratoma	..	..	..	..	1	..	1
Dermoid	..	..	1	..	1	..	2
Inflammatory-reaction processes:							
Tubercle	..	2	1	..	5	..	8
Gumma	..	..	..	..	1	..	1
Cysts	4	4	2	..	..	..	10
Unclassified:							
Hydatid	1	2	4	..	4	..	11
Psammoma	7	1	1	1	3	..	13
Sarcoma	10	10	8	4	32	2	66
Not stated	5	4	5	7	19	2	42
TOTAL	60	64	38	19	145	4	330

from the reports of operation upon 113 cases, diagnosed as sarcomata, 14 are reported as recovered and 18 as greatly improved (Table XXX).

TABLE XXX

Pathological Diagnosis	Recovered	Greatly Improved
Fibrosarcoma	4	6
Fibromyxosarcoma	..	1
Chondrosarcoma	..	1
Osteofibrosarcoma	1	..
Angiofibrosarcoma	..	1
Lymphosarcoma	..	1
Neurofibrosarcoma	1	..
Sarcoma	6	8
	14	18

TABLE XXXI

PROGNOSIS AS TO AGE

Age	Recovery	Greatly Improved	Slightly Improved	Unimproved	Death	Not Stated	Total
1– 9	2	..	..	1	1	..	4
10–19	7	5	4	2	5	1	24
20–29	11	10	4	3	32	1	61
30–39	5	18	8	4	27	1	63
40–49	20	8	14	5	36	1	84
50–59	4	9	3	2	21	..	39
60–69	2	5	1	1	8	..	17
Not stated	9	9	4	1	15	..	38
TOTAL	60	64	38	19	145	4	330

The age of the patient is a factor in the mortality only in so far that a larger proportion of benign tumors were found in those under rather than over twenty years of age. Out of twenty-eight operations for the removal of spinal growths in patients under twenty years of age there were but six deaths (Table XXXI). It is interesting to note in this connection, however, that Rocher has recently removed a sarcoma from the transverse processes of the eleventh and twelfth thoracic vertebrae in a baby thirteen months old. The operation was supplemented by radiotherapy, and six months later the child was reported as being in good health and able to walk and run in a normal manner.

Statistically the prognosis is practically the same for both sexes, the mortality being 46.7 per cent in males, 40.7 per cent in females, and 42.3 per cent in 26 cases in which the sex was not given (Table XXXII).

TABLE XXXII

PROGNOSIS AS TO SEX

Sex	Recovery	Greatly Improved	Slightly Improved	Unimproved	Death	Not Stated	Total
Male	31	27	20	10	79	2	169
Female	23	31	16	8	55	2	135
Not stated	6	6	2	1	11	..	26
TOTAL	60	64	38	19	145	4	330

Final Results.—The true estimate of surgical attainment in the treatment of spinal tumors must be measured in terms of end results. The three-year limit arbitrarily chosen as the period which must elapse without

recurrence after operations for malignant growths elsewhere has never been applied to spinal tumors. In point of fact the vast majority of cases are placed on record before three years, many, indeed, before one year or even a few months have elapsed. That a proper prospectus may be had of the end results of operation, I have eliminated all cases in which there was an interval of less than a year between the time of operation and the publication of the report, and have gathered from the 330 records those which survived respectively from one to eight years (Table XXXIII). To this list no doubt a number of other successful operations might be added were it possible to secure the latest reports. So that the figures about to be quoted must be accepted with this reservation.

To epitomize the salient facts in Table XXXIII: Of 35 cases that had survived the operation from one to eight years, 31 had entirely recovered or were greatly improved. The largest number of these, 27, were of meningeal origin, 18 extradural and 9 intradural; the largest number, 13, were diagnosed benign growths; next in order sarcoma, 11; and closely following endothelioma, 9. The longest recorded period of survival for gliomata was two years; the longest period of survival for intramedullary growths was five years, for vertebral and for caudal tumor three years.

In one of my cases in which I removed an intradural endothelioma from the level of the fifth cervical vertebra, the end results have been very nearly perfect; the patient is now living and practically well eight years after the operation. There have been no evidences of recurrence and there is but a slight residuum of the functional disturbance present before the operation.

A case of endothelioma of the cord at the level of the fifth cervical vertebra. The tumor, an endothelioma, was removed eight years ago and there has been no recurrence of symptoms.

The patient, a woman, *aet.* 33, was admitted to my service at the University Hospital, February 22, 1910 (File No. 6179). She had been married eight years, had two children, and had always enjoyed the best of health, except for occasional fainting spells, the last of which occurred eight years ago. Two years previous to her admission, pain began in the back of the neck and left shoulder which somewhat resembled rheumatism and was treated as such. Later the pain, which was sharp and shooting in character, came in intervals, lasting from five to twenty minutes, and gradually extended down the arm. There was also a sensation of numbness in the left arm, leg and foot, and later a decided weakness on the left side.

Physical Examination.—Sensory Disturbances. Careful examination over the whole body failed to reveal any definite impairment of tactile, pain or temperature sense. There was a very moderate impairment of the sense of position in the left hand, but this was by no means constant. *Motor Disturbances.* The grip of the left hand was less than that of the right, the discrepancy being more than would naturally obtain in a normal right-handed person. In the left upper extremity,

TABLE XXXIII

Final Results in Cases Surviving Operation for Spinal Tumor

Location, Origin and Character of Tumors		1–2 Years After				2–3 Years After				3–4 Years After				4–5 Years After				5–6 Years After				6–7 Years After				7–8 Years After				Total
		Recovered	Greatly Improved	Improved	Unimproved	Recovered	Greatly Improved	Improved	Unimproved	Recovered	Greatly Improved	Improved	Unimproved	Recovered	Greatly Improved	Improved	Unimproved	Recovered	Greatly Improved	Improved	Unimproved	Recovered	Greatly Improved	Improved	Unimproved	Recovered	Greatly Improved	Improved	Unimproved	
Location	Cervical	2			1	2			1						1								1				1			9
	Cervicothoracic	2																		1										3
	Thoracic	2	1			3	2		1	2				1	1			2				1								16
	Lumbar	1				1	1	1		3																				7
																														35
Origin	Meningeal (Intradural)	5	1			3	2		2	1										1		1	1				1			18
	Meningeal (Extradural)	1			1	1		1		1				1	2			1												9
	Intramedullary					1												1												2
	Vertebral									2																				2
	Caudal	1					1			1																				4
																														35
Pathological diagnosis	Glioma	1				1																								2
	Sarcoma	2			1		1		1	2				1	1			1		1										11
	Endothelioma	2				2			1	1												1	1				1			9
	Benign growths	2	1			3	2	1		2					1			1												13
																														35

as in the lower extremity of the same side, amplitude of motion was somewhat restricted due to muscular weakness, although there was no decided paralysis. *Reflex Disturbances.* The scapulohumeral reflex was slightly greater on the right than on the left, as was also the coracobrachial and the biceps tendon reflex. In the lower extremities the reflexes were all increased, those of the left side being greater than those on the right. A Babinski reflex was present on the left, but not on the right. There was no ankle clonus on either side. Tonicity of the upper extremities and the right lower limb was about normal, but that of the left lower limb was

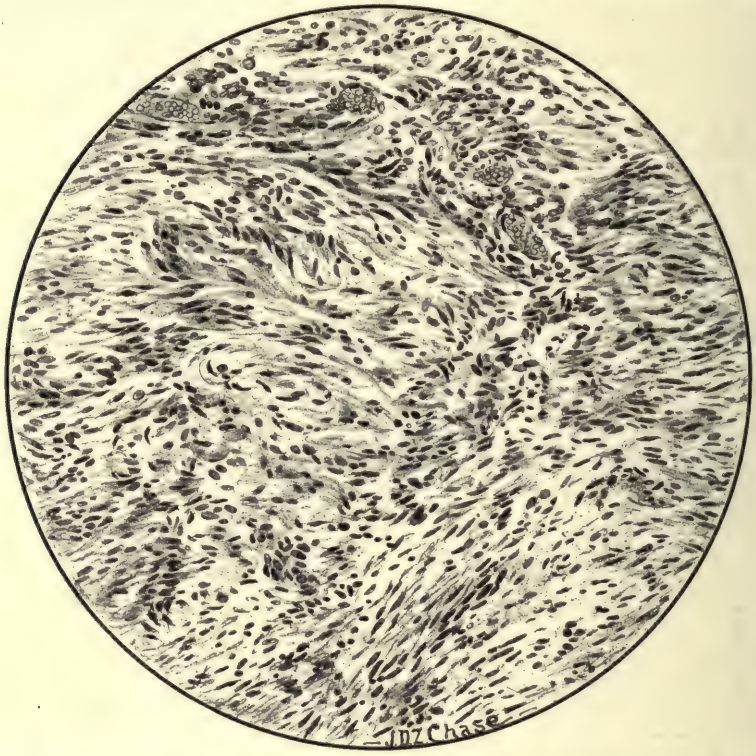

FIG. 258.—MICROSCOPICAL DRAWING OF AN ENDOTHELIOMA OF THE DURA. (University Hospital, File No. 6179.)

somewhat increased. There were no electrical reactions of degeneration in the left upper extremity.

The *roentgenogram* showed a shadow to the outer side of the fourth and fifth cervical vertebrae on the left. The mass was small and lay in such a position that it might readily catch the posterior roots and press on them. The left halves of the fourth, fifth and sixth vertebral bodies seemed a little denser than did the right.

Laminectomy, February 25, 1910. A semilunar skin flap was reflected and an incision made to the left of the median line. By means of a chisel the muscles and fascia were stripped from the underlying vertebrae. The spinous processes of the fourth, fifth and sixth cervical vertebrae, the laminae of the fifth cervical and a portion of the sixth cervical vertebrae were removed. There was very little hemorrhage and the dura was then opened, exposing a small tumor about the size

of a chestnut, located a little above the level of the fifth cervical vertebra. The posterior root of the sixth cervical segment ran over the mass, and it was impossible to say whether the anterior root ran through it. The posterior root of the fifth cervical segment was in contact with the upper end of the mass. The tumor was very friable, and in removing it there was marked twitching of the left shoulder.

Pathological Report.—The growth was composed of cells which belonged distinctly to the connective tissue group. They were usually spindle-shaped, arranged in fasciculi which formed interlacing whorls. In some places the tissue was very loose, almost embryonic in character. There was no stroma save that furnished by the processes of the tumor cells. The growth was irregularly canalized by blood vessels, and appeared well nourished. There was some free hemorrhage into the tissue. No mitotic figures were seen. The appearance corresponded to that of an endothelioma (Fig. 258).

FIG. 259.—PHOTOGRAPH OF PATIENT EIGHT YEARS AFTER THE REMOVAL OF AN ENDOTHELIOMA FROM THE DURA AT THE LEVEL OF THE SIXTH CERVICAL SEGMENT.

Partial recovery of function with some residual weakness in the forearm.

The patient made an uneventful recovery, and eight years after the operation is still living and practically well. Her general nutrition is excellent and she now weighs 190 pounds. There are no muscular atrophies or hypertrophies; the tonicity of the left arm is greatly increased, and the reflexes exaggerated. The patient reports eight years after the operation that the use of this arm has returned for all practical purposes, cold alone decreasing the freedom of activity (Fig. 259). The grip in the left hand is not so strong as in the right. No pain is experienced in the shoulder where formerly it was most marked, and there are no pains in the left side of the body below the shoulder level. However, an occasional pain is felt in the region of the scar on the neck, and severe radiating pains, occurring at intervals varying from two weeks to a month, and being at present of less severity, involve the left arm and forearm and extend into the fingers. Heat and cold sensations are about normal in the arm, forearm and hand, and patient is able to recognize objects in the left hand. There is still, however, some abnormal sensation in the left forefinger, described as a tight and distended feeling. In the left lower extremity all reflexes are greatly exaggerated and all sensations intensified, while in the right lower extremity all sensations are subnormal and the reflexes decreased. The sphincters are normal. Ankle clonus and the Babinski signs are present and the patellar reflexes exaggerated on the left side. The gait is normal with the exception of a slight spasticity in cold weather.

Resume.—A careful and critical analysis of the symptomatology of spinal tumors might leave one with the impression that there were still gaps to be filled in before a diagnosis could be made with reasonable certainty. This criticism might hold in exceptional cases, but certainly not in the larger number. Because of the distance traversed by the nerve-root from its point of origin to its point of exit it may not always be possible to state precisely at what level or laminae the tumor is situated, but for these doubtful cases, the rule which I have followed and have described in exploration makes ample provision.

Certain it is that delay in operation is no longer justifiable when the suspicion of tumor cannot be excluded. The exploratory laminectomy is an operation which of itself involves little risk, and the fear of opening the dural sac should not stand in the way of this means of confirming a diagnosis and the relief that may come from the finding and removal of the tumor.

The results, both immediate and terminal, it has been clearly shown, are good, bad or indifferent according to whether the operation were in the early or terminal stage of the disease. The emaciated, exhausted patient with decubitus, cystitis and pyelitis is not an ideal surgical subject. The wreckage of a pressure myelitis of long standing must be credited to the account of the physician and not the surgeon. Early diagnoses and operations mean not only more lives saved, but more function restored.

The technic of laminectomy has reached a stage of refinement that makes larger exposures possible and a larger percentage of tumors accessible. A larger proportion of tumors of the spine than of the brain belong in the category of benign growths, and even malignant tumors, such as sarcoma and endothelioma, involving the cord and its coverings, are not so prone to recurrence as similar growths elsewhere. The survival of a patient eight years after the removal of an endothelioma is an index of what may be accomplished in the surgery of spinal tumors.

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CHAPTER IX

MENINGITIS

In discussing the various types of inflammation of the spinal meninges and their concomitant symptoms, one should never lose sight of the anatomical relations, but should bear in mind that the picture is very largely the outward expression of the mechanical factors obtaining.[1]

PACHYMENINGITIS

The dura mater is rarely, if ever, primarily involved in an inflammatory process; but it is the frequent seat of secondary involvement (Fig. 260). Owing to its extremely dense nature, we find morbid processes acting on the external or the internal surface, but only late in the course of the affection do we find the membrane completely eroded or involved in its entirety. Therefore, we have, *a priori,* pachymeningitis externa and pachymeningitis interna.

Pachymeningitis Externa.—This type of meningitis is usually secondary to disease of neighboring structures, such as tuberculous or syphilitic disease of the bodies of the vertebrae, purulent infection of the pleura or abdominal viscera, or decubitus, the latter chiefly of the sacral region. The *mode of involvement* of the dura may be either by direct extension or by extension through blood and lymphatic channels. In *tuberculous pachymeningitis* the former condition obtains; the bodies of the vertebrae become the seat of a tuberculous process, which sooner or later results in caseation. The mechanical stress on the spinal column causes the diseased vertebral body to collapse, usually at its anterior aspect. In this manner, a mass of broken-down detritus and tuberculous granulation tissue is forced backward against the external surface of the dura. There may be so much of this material extruded posteriorly that it at once encroaches upon the lumen of the spinal canal sufficiently to give symptoms of compression of the spinal cord. This is more likely to be the case when some sudden stress causes a traumatic kyphosis in a previously tuberculous spine. In such an event, we do not postulate a tuberculous pachymeningitis externa, as prior to the traumatism the dura may not have been brought

[1] For a complete description of the anatomical relations of the meninges, *see* Chapter on Anatomy, page 48. The classification of the meningitides has always rested on an anatomical basis. Following this precedent, we have inflammation of the dura mater, pachymeningitis, and inflammation of the pia-arachnoid, leptomeningitis.

sufficiently in contact with the diseased focus to become itself the seat of the process. But, sooner or later, the extension takes place, and there is present at the level affected a greatly thickened dura, showing the tuberculous granulation tissue and areas of caseation. Even in this condition of affairs, it is surprising how free from change the inner aspect of the dura remains. It is a demonstration of the great protective value of fibrous tissue. Of course, if the patient live long enough and the process be not halted, it is only a question of time before tubercles appear on the inner surface; and from this point, the subsequent involvement of the leptomeninges is quite certain and rapid.

FIG. 260.—SPINAL PACHYMENINGITIS. (Courtesy of Dr. William G. Spiller.)

There are cases in which tuberculosis of the bodies of the vertebrae is discovered before any kyphosis has occurred, and the patient is placed at rest and under the most favorable hygienic conditions. Under such treatment there may be a slow improvement, resulting in an ankylosis of the diseased vertebrae, and what is, practically considered, a cure; or the process of granulation and caseation may continue, and at a later date, though the patient may have been protected with a plaster cast and extension, symptoms of involvement of the dura may develop. Even in such an unfortunate eventuality, the prognosis is not necessarily bad. There are many instances on record in which the dura has been involved, and yet, under correct orthopedic and hygienic treatment, the patient has made a practical recovery. Unfortunately, there is a grave restriction, so far as surgical interference in these cases is concerned. No one would elect to operate through a tuberculous area; and even allowing that the diseased dura could be effectually exposed without risk, the process would,

in all probability, be too diffuse to remove. There is, therefore, only one indication which can justify an exploratory laminectomy in these cases, and that is where the symptoms of compression of the spinal cord are certain and progressive, and where conservative measures have been tried and have failed. The vertebrae most frequently the seat of tuberculosis are the seventh thoracic to the second lumbar, although cases are on record where even the axis or atlas has been involved. Tuberculous pachymeningitis externa must be reckoned among the chronic processes.

In cases of extension of other infections by way of the vascular or lymphatic channels, we have to deal with a more acute condition. The etiology of *non-tuberculous pachymeningitis externa* is, in the vast majority of cases, comprehended in the precedent condition of decubitus, the microörganism being carried to the external surface of the dura by the lymphatic circulation. Cases of erysipelas have been reported in which there was a secondary external pachymeningitis of probably streptococcic nature. Should recovery take place after a severe involvement of the external surface of the dura, one might postulate a condition of local adhesion between the dura and the posterior aspect of the bodies of the vertebrae, which might lead to a certain amount of spinal immobility. Occasionally in malignant disease of the vertebrae there is an inflammatory reaction in the external surface of the dura mater which later becomes the seat of a purulent infection.

The *symptoms* of pachymeningitis externa may be classified as sensory and motor. The sensory symptoms are due to irritation of the posterior roots at the point of emergence from the dural sheath as well as irritation of the sympathetic supply of the dura itself. The meninges, it should be remembered, are supplied by fine afferent fibers, recurrent from the gray rami communicantes. These are homologous to the splanchnic afferents, and what is said regarding the sensory nature of the latter in the chapter on physiology should be borne in mind here. Usually there is pain in the back which is augmented by movement. In case there is little involvement of the posterior roots this may lack the sharp, lancinating character, but sooner or later the latter obtains and is then of segmental distribution, radiating to the periphery. Often the pain is initiated or increased by the acts of coughing or sneezing. In case the meningitis chiefly involves the thoracic portion of the theca, the distribution is girdle in character, having a tendency to be wider than that which is found in cases of tabes, depending, of course, on the longitudinal extent of the process. In the early stages of the process the involvement of the posterior roots may cause areas of hyperesthesia, hypesthesia, or paresthesias of different types. The location of these areas corresponds to the level of the cord involved. Unfortunately when these symptoms are early in the course of the trouble they do not receive the attention they deserve. When the lumbosacral region is involved, there may be a symptom picture

at first not unlike bilateral sciatica. When either the cervical or lumbosacral level is the seat of the process, it is only a question of time before there are motor symptoms due to the involvement of the anterior roots. This is manifest, first, in clonic jerking of the part, later, in a more or less profound paresis. The diagnosis of this condition must rest largely on the precedence of a neighboring bone lesion or process of suppuration. The roentgenographic examination will demonstrate the former and a careful physical investigation with blood examination will indicate the latter.

The *prognosis* of this condition, though varying with the etiology, is in all cases grave. A tuberculous pachymeningitis externa may be of very slow progress, but, if there be tubercles actually in the pachymeninges, it is unlikely that cure is possible. Many of the cases of suspected tuberculous pachymeningitis externa secondary to caries of the vertebrae are in reality conditions of meningeal irritation and not tuberculous involvement; in other words, there is as yet no tuberculous process in the dura. These are the cases which under the best hygienic treatment occasionally get well.

Tuberculous spondylitis of the lower thoracic vertebrae in an adult with development of symptoms suggestive of secondary involvement of the pachymeninges

The patient, a male, *aet.* 43 (File No. 30831), was admitted to the University Hospital, December, 1915. The family history was negative and he denied venereal infection. In 1892, when twenty years of age, he had had an abscess in his right lung which discharged large quantities of exceedingly foul pus. In course of time he recovered from this and remained well up to the fall of 1908, when he developed pain in the right lumbar region, the cause of which proved to be a cold abscess which was aspirated three times in January, 1909. By March, 1911, he had developed a "bump on his spine" and in July of the same year began to wear a brace, which he used until the summer of 1912.

His present condition dated from a long and rough automobile trip during September, 1915, after which he experienced an "odd feeling" in his left foot on walking downstairs. This, according to his description, was most probably an ankle clonus. By October 15, 1915, weakness in the bladder and rectum had developed and he experienced some tight feeling in his abdomen and pain in the lower thoracic region.

Physical Examination.—The motor power of his lower limbs was excellent but all the reflexes of the lower limbs were exaggerated and Babinski reflex was well developed on both sides. Irritation of the skin over the rectus abdominalis on the lower part of the abdomen produced no response, but similar irritation over the upper third of this muscle produced a most marked reflex action of the upper segment of this muscle. *Sensation.* Tactile and thermal sensations were preserved and normal over the entire body. There were four areas of hypalgesia which might be located as follows: a circle about 5 cm. in diameter at the left internal malleolus; an oval, 7.5 x 10 cm., long axis vertical, at the inner aspect of the left knee; an indistinct circular area, 7.5 cm. in diameter, on the anterior aspect of the upper third of the left thigh; and an indistinct area, 7.5 cm. in diameter, at the inner

aspect of Poupart's ligament on the left. He was greatly troubled by involuntary jerking in his lower limbs, especially at night.

Roentgen examination was as follows: Two lesions were present. First an almost complete disappearance of the intervertebral disk between the bodies of the eighth and ninth thoracic vertebrae, the space between being narrowed to about 2 mm. The vertebrae were straight and the bodies of about normal density. The lower border of the eighth and the upper border of the ninth thoracic vertebrae were perhaps slightly irregular in outline. The space between the ninth and tenth thoracic vertebrae appeared normal. There was a condensation and fusion of the bodies of the tenth and eleventh thoracic vertebrae and bone proliferation on each lateral aspect at about where the intervertebral disk should be. The two fused vertebrae equaled about one and one-third times the size of the body of the vertebra next below. The fusion had produced a slight kyphosis and a slight lordosis to the right. The total shadow of the two vertebrae was a little more dense than the body of the vertebra below. This had the appearance of a healed lesion, the active lesion being between the eighth and ninth thoracic vertebrae. The fifth, sixth, seventh and twelfth thoracic vertebrae appeared normal.

The patient was examined by Dr. Alfred R. Allen, whose diagnosis was as follows: "There is a pressure on the spinal cord due to disintegration of the tenth and eleventh thoracic vertebrae, possibly of the eighth and ninth. This is very likely a tuberculous process and the symptom picture may well be explained by a tuberculous involvement of the pachymeninges secondary to the primary tuberculous spondylitis."

The patient was sent to the seashore January 14, 1916. From that time until March, 1917, the patient was kept in a plaster-of-Paris jacket and with the exception of the eight weeks preceding was kept flat on his back. His physical condition improved, he looked the picture of health and had gained about forty pounds. The notable change in the symptoms above noted was the disappearance of pain and of the clonic spasms of the lower extremities, at one time a very distressing feature. During the eight weeks he was allowed to sit at an angle of forty-five degrees and since then there have been occasional clonic spasms of the extremities.

The *treatment* resolves itself into an attack on the original process and may be effective, so far as the meninges are concerned, only where the dura has not become actually involved by the tuberculosis or the malignant growth.

Pachymeningitis Interna.—As in the external variety, so also in the internal, the condition is usually an extension by contiguity; in this case the primary focus is most often the pia-arachnoid. In the vast majority of cases, the inflammation is purulent in type, and the large variety of microörganisms found includes Diplococcus intracellularis meningitidis, Spirochaeta pallida, pneumococcus, Bacillus influenzae, tubercle bacillus, streptococcus, Staphylococcus pyogenes, Bacillus typhosus and gonococcus. Inflammatory thickening and exudate are the rule in internal pachymeningitis and there soon ensues, if the patient survives long enough, a matting together of all the spinal meninges about the periphery of the cord, causing the condition known as meningomyelitis. This is particularly apt to happen in the syphilitic variety, and is also frequently found at *post-mortem* examination in cases which have recovered from epidemic cere-

brospinal meningitis and have subsequently died from some other cause. Occasionally in such cases plaques on the meninges are discovered at autopsy, as in Fig. 261.

Church has described a form of spinal pachymeningitis interna which is the homologue of internal hemorrhagic pachymeningitis of the cranial cavity, but this affection must be of extreme rarity. Besides showing the hemorrhagic, laminated structure of the cerebral type, it also is associated with syphilis. Except for Church's description, I have been unable to find any report on this type of spinal meningitis.

FIG. 261.—PLAQUES IN THE SPINAL PIA. (Courtesy of Dr. William G. Spiller.)

As an aid to diagnosis it is well to bear in mind the clinical course of cases of internal pachymeningitis, depending on the particular type of infection. To this end we may divide cases into three classes: first, those caused by the Diplococcus intracellularis, the streptococcus, the staphylococcus, pneumococcus and the Bacillus influenzae; secondly, those cases due to the tubercle bacillus, and lastly, those caused by syphilitic infection. The first class is of rapid, at times fulminating, character; the second is more subacute in progress, while the third is of slow development. As in pachymeningitis externa, a precedent lesion should always be sought and, when found, is often a reasonable assumption as to the etiology.

Pachymeningitis Cervicalis Hypertrophica.—This condition may be defined as a gross, exudative thickening and welding together of the spinal meninges, usually limited in vertical extent to the four lower cervical and two upper thoracic segments. This forms an annular band about the cervical enlargement, which is usually more pronounced in the posterior than in the anterior aspect. The *cause* of this condition, like many others in neurology where ignorance is more than usually profound, has been ascribed to alcohol, exposure to inclement weather, syphilis and trauma. It were well to call attention to the possibility of irritation or secondary infection of the dura from a precedent hemato-

rachis, a subject which will be found under the heading of hematorachis.

The *symptoms* depend on the particular level first involved. Usually the first signs are due to irritation of posterior nerve roots, in which case we have pain in the back, more or less severe, and also of radiating character in the upper extremities. Often the latter may be initiated or increased by forcible passive flexion of the head downward on the chest, this causing tingling or lightning-like pains to shoot down the upper limbs into the fingers. There is a tendency to symmetrical involvement and, therefore, to a symmetry in symptomatology. The progress is slow, and little by little, as the process increases, areas of anesthesia for the various forms of sensation appear in the distribution of the brachial plexus. Following the onset of sensory symptoms, motor disturbances appear, due to involvement of anterior roots. If the process be more advanced in the upper part of the cervical enlargement, the consequent paralysis and wasting are first seen in the shoulder-girdle and muscles of the upper arm. Babinski, Jumentié and Jarkowski reported such a case, in which the sensory disturbance was almost negligible. This, of course, indicated that inflammatory thickening was located chiefly anteriorly, and that the posterior roots were but little affected. Diagnosis in such a case becomes difficult. But if, as frequently happens, the involvement be more pronounced about the eighth cervical and first thoracic segments, there ensue atrophy and paralysis of the intrinsic muscles of the hands. In any case, the paralysis of the upper limb is of the lower motor neuron type, paralysis or weakness, flaccidity, loss of reflexes, atrophy and electrical reactions of degeneration. Here, as elsewhere, increase in fibrous tissue means, sooner or later, fibrous tissue contraction with consequent destruction of parenchyma. As soon, therefore, as annular pressure about the spinal cord takes place, symptoms of upper motor neuron involvement below the lesion slowly develop; the patient becomes progressively weak and spastic in the lower limbs, and finally completely paralyzed, with sensory disturbances and loss of control of bladder and rectum.

The sensory symptoms differentiate this condition from amyotrophic lateral sclerosis and progressive spinal muscular atrophy, and the lack of dissociation of sensibility and the presence of a wide and symmetrical development of symptoms render the diagnosis of intramedullary tumor improbable. Syringomyelia, though at times giving the picture of a similar motor disturbance, is not accompanied by the intense pain, nor is the upper motor neuron paralysis likely to be of so profound a character. Also in syringomyelia we find the dissociation of sensibility which fails in hypertrophic cervical pachymeningitis.

The result of *surgical interference* will depend on whether there be adhesions to the periphery of the cord. In some cases, careful longitudinal incision through the meninges will demonstrate that the dense, fibrous ring may easily be peeled away from the cord surface. These are the cases

in which one may expect benefit from surgical treatment. In any case, exploratory laminectomy should be performed, and the meningeal covering incised; and if dense adhesions be found, although the operation may be of no avail, at least no material damage is done. Where the Wassermann reaction indicates syphilis, an intensive antisyphilitic course of therapy is indicated. Unfortunately not much can be expected from such means. Various efforts at intense counterirritation have been advised, but, as might be expected, have usually proved of no benefit.

Pachymeningitis cervicalis hypertrophica in a young man. Decompressive laminectomy, separation of adhesions; temporary improvement followed by return of symptoms and death.

The patient, a male, *aet.* 29 (File No. 26130), was admitted to the University Hospital, November, 1913. In regard to his past medical history, he denied venereal disease but had had rheumatism in 1904. History of the condition present on admission: In March, 1913, he began to have pain and soreness in the left shoulder and in the left side of the neck and chest with occasional cramps in his fingers. The pain was not radiating in character. Since the latter part of July, 1913, these symptoms were not so severe as during the prior four months.

Physical Examination.—Motor function. There was weakness in both upper extremities, but this was only slight on the right side. On the left, there was considerable wasting of the shoulder muscles and muscles of the arm. The whole extremity was flaccid and weak and there was complete inability to extend or flex the forearm on the arm, while the grip of the left hand was markedly diminished. The biceps and triceps reflexes on the left were absent. In the right upper extremity there was some slight wasting of the shoulder girdle muscles, but the weakness of this limb was not pronounced and the reflexes were, if anything, somewhat prompt. *Sensory function.* There was impairment of pain and temperature sensation over the anterior surface of the left shoulder, on the anterior half of the inner and outer surfaces of the left arm and on the outer portion of the flexor surface of the left forearm as well as the outer half of the palmar surface and the whole dorsal surface of the left hand. There was a less marked impairment of the corresponding areas of the right upper extremity. Tactile sensation was unimpaired over the entire body. To the right of the right nipple line there was impairment of pain sensation, and pain stimuli were perceived as cold in the lower right portion of the body below the crest of the ilium and over the whole right lower extremity with the exception of the sole of the foot and the dorsal surface of the toes. The motor power of the left lower limb was greatly decreased, but that of the right was not much affected. The reflexes of the lower limbs were normal and the Babinski phenomenon was not obtained.

Laminectomy, November 29, 1913. The laminae of the fifth, sixth and seventh cervical vertebrae were removed and on the dura being opened the fluid spurted out as though under great tension. On the right side, at the points of origin of the fifth, sixth and seventh cervical nerves and also at their points of exit from the canal, there was no evidence of new growth, but throughout there were adhesions between the membranes and cord which were separated with difficulty and bled freely. The same condition obtained on the left side. During the manipulation of the cord the blood pressure dropped to 88 mm. The subsequent history of this case until the discharge from the hospital, March 25, 1914, shows gradual improvement in motor function of the left upper and lower extremity. There developed a

tendency to flexion contracture of the fingers of the right hand. From the time of the operation to discharge there was almost continuous sweating of the right side of the face. After discharge from the hospital there was a gradual increase in all symptoms leading to complete quadriplegia and death two months later.

LEPTOMENINGITIS

I have already touched upon the etiology of inflammation of the pia-arachnoid; and before proceeding further in the discussion of types, it seems desirable to picture the relation between the clinical manifestations of incipient meningeal irritation and the development of the process from a pathological standpoint.

Frequently in children and also to a less extent in adults, in the course of an infectious fever, typhoid, pneumonia, diphtheria, scarlatina, influenza and others, the following **symptom picture** will develop: The patient will complain of pain in the back, possibly radiating into the limbs, and some stiffness of the muscles of the spinal column, particularly in the cervical region. Extreme irritability, both mental and physical, will be present, as well as a tendency to drowsiness and scaphoid abdomen. A lumbar puncture may reveal a slight increase in pressure, but no cloudiness of fluid and no cytological abnormality. With the amelioration of the primary disease, there is a gradual mitigation of the symptoms above noted, and the patient eventually makes a complete recovery. What is the explanation of the nervous phenomena in such a case? At first, the physician, very naturally, considers the diagnosis of meningitis, and gives a guarded or grave prognosis. In his own mind, he feels that the diagnosis is correct and the chances of recovery few. With the disappearance of the symptoms and rapid recovery of the patient, he questions to himself, if not to the family, the validity of his first opinion.

In order to understand the question, important to the general practitioner and surgeon, as well as to the neurologist, one must realize the possible action of a circulating toxin or irritant on the leptomeninges. The first effect may well be an abnormal passage of serum through the walls of the fine capillaries of the pia-arachnoid into the perivascular tissue. This may or may not be followed by a determination of leukocytes about the vessels. In any case, enough of mechanical disturbance has now obtained to interfere materially with the reciprocal relationship normally present between cerebrospinal fluid and the blood vessels. It is probable that the interchange between the vascular system and the cerebrospinal fluid is a very important function in the subarachnoid space about the spinal cord; therefore, blocking this means of maintenance of equilibrium between them leads directly to an increased amount of cerebrospinal fluid, which, of course, postulates increased pressure. Could the pia-

arachnoid be examined at this stage, it would possibly be difficult to note any gross change; the cerebrospinal fluid would be clear; possibly distention of the pia-arachnoid would be noted, and it is likely that some fine vascular distention would be evident. Let us realize that this condition has been caused by a circulating irritant or a circulating toxin; the toxin owes its presence to the action of the microörganisms causing the disease, but we have no reason to believe that at this stage the microorganisms themselves are in the spinal meninges. Now the disease abates, owing, let us say, to a developing autogenous immunity or to an amelioration of the condition producing the circulating irritant, the latter exemplified in uremia, and thus the irritant or the toxin is no longer supplied and what there is disappears in the case of the irritant, or becomes counteracted by an antitoxin if it be a toxin. The blood vessels and perivascular tissue of the pia-arachnoid return to normal with a consequent reduction in cerebrospinal fluid pressure.

The name given to this clinical picture is *meningism,* first used by Dupré in 1894, and its course, as above outlined, is the favorable termination. Let us now suppose that the patient's resistance to the infection is low, and that the circulating toxin increases, rather than abates. In such a condition we may imagine that the changes are much more pronounced; many fine blood channels may be permanently isolated from the interchange of the cerebrospinal fluid, by reason of a surrounding layer of leukocytes and fine coagulum. So although all interchange be not blocked, yet the equilibrium is seriously disturbed, and the subarachnoid space is greatly distended with fluid, still clear and with no marked cytological change. This is the condition known as *serous meningitis,* and the most important factor in the argument is that up to this point there is *not necessarily* any microbic invasion of the meninges. The ubiquity of microörganisms in the body may be evidenced by a bacteriological examination of the intestinal flora, and the constant presence in the tonsillar secretions of various strains, benign and pathogenic. In supposedly healthy subjects, examination of the secretion from the mouth reveals staphylococci, streptococci, pneumococci and Pfeiffer's Bacillus influenzae. Now, where meningeal changes have progressed to the stage of serous meningitis, one must postulate a lowered vitality or resistance in the meningeal tissue, which, at any time, may become the host of the particular microörganism causing the primary disease, or of some coexisting strain of another organism, possibly a mixed infection. Therefore, serous meningitis may be without microörganisms in the meninges, the amicrobic serous type of Quincke, or microörganisms may be present. As soon as the microörganisms in the meninges cause an extravasation of leukocytes into the surrounding tissue and cerebrospinal fluid, the latter becoming turbid, we designate the condition *purulent meningitis.* It is, therefore, legitimate to hold that these three stages, meningism, serous

meningitis and purulent meningitis, are necessary and sequential. Had we the means to determine the condition precedent, we should find that every case of acute serous meningitis was preceded by meningism; and every case of purulent meningitis by serous meningitis, though possibly of short duration. It will be noted that in the preceding sentence I use the qualification "acute" serous meningitis; this is necessary, because a slowly developing, chronic serous meningitis would very likely give no syndrome of meningism. Maloney makes the statement that every microorganism which has ever been identified with serous meningitis is capable of causing the purulent form. The same microörganisms which are enumerated as possible causes for pachymeningitis interna are here likewise the **etiological factors.** But we must consider at this place the possibility of lead as a factor and take up the discussion of the gonococcus as a cause. This latter question has caused much argument, many denying that a true case has ever been made for the validity of the gonococcus as the etiology of leptomeningitis.

Lead poisoning may cause spinal meningitis, serous in form as well as with turbid spinal fluid. Maas reported a case of serous meningitis in plumbism, in which there was histological change in the pia-arachnoid. Mosny and St. Gerons reported a case of severe spinal meningitis in which the turbid cerebrospinal fluid showed a marked lymphocytosis, but in which recovery ultimately ensued.

The doubt which formerly obtained as to the possibility of a Neisserian meningitis has in recent years been removed. Henderson and Ritchie studied a case with extreme care, in order to evaluate the evidence in favor of the gonococcus being a possible etiological factor. I quote their conclusions:

1. A man, aged twenty-three, developed acute cerebrospinal meningitis—and subsequently a polyarthritis—eight days after acquiring a gonorrhea. He made a complete recovery without any specific antimeningococcal treatment being employed.
2. Gonococci, but no meningococci, were obtained from the urethral discharge.
3. The only microörganisms detected in the cerebrospinal fluid were scanty intracellular, Gram-negative diplococci, with their apposed surfaces flattened.
4. All efforts to obtain cultures from the cerebrospinal fluid and from the blood were unsuccessful.
5. A young guinea-pig and three mice remained well after having been inoculated intraperitoneally with the cerebrospinal fluid.
6. The patient's blood agglutinated gonococci readily, but it had only a slight agglutinative action upon meningococci.
7. The patient's blood serum contained a thermostable gonococcal immune body, but not a meningococcal one.

Bruce and Shennan have reported a case of acute hemorrhagic meningitis, the origin of which was the anthrax bacillus. The leptomeninges were chiefly involved, although the organisms were also found in the adventitious sheaths of the blood vessels within the spinal cord.

Much that has been said concerning the **symptomatology** of pachymeningitis also obtains in the involvement of the leptomeninges. We may divide the symptoms into motor, sensory and toxic. The *sensory symptoms* are of two types: the irritation of posterior roots and the irritation of the sensory supply of the meninges. According to the level involved, there is no part of the body which may not be the seat of pain. This may be varied in character in the same patient; in some distributions, a deep-seated, dull ache is present, or the patient complains of a superficial soreness. The sharp "lightning pains," so characteristic of posterior root irritation, are of frequent occurrence. Occasionally perversions of sensation are noted, such as an area in which there is a feeling of intense cold or burning, or other paresthetic phenomena. If the meningitis be localized and fairly symmetrical, the sensory symptoms, pains and anesthesia, may definitely indicate the level of involvement; but in the diffuse variety, one is surprised and dismayed at the utter lack of localizing signs. In these cases, irregular areas of all types of sensory disturbance are found. To be sure, the irregularity of distribution in widely separated parts of the body, as well as the lack of spinal segmental or nerve trunk character of the areas, is of diagnostic value in that it strongly suggests a diffuse meningeal lesion.

The *motor symptoms* vary from slight weakness of a limb or group of muscles to complete paralysis. These motor phenomena may be due to the action of toxins on the anterior roots, to infiltration of leukocytes and serous exudate in the anterior roots, to pressure on the anterior roots by swelling of the leptomeninges at their point of exit from the spinal cord or of the dura at the intervertebral foramina. It will be understood that in some of these conditions the weakness or paralysis is temporary; in others, permanent. The disappearance of paralysis is usually gradual, at times months elapsing before power is restored. Occasionally we meet with a case in which motor symptoms are severe, but in which there is a sudden clearing up of the paralysis, though the sensory phenomena persist. This condition is difficult to explain, but I think we can say, *a priori,* that any sudden amelioration in motor symptoms must postulate toxic and not microbic origin; although in the same case the posterior roots may be the site of a more deep-seated change, and the cerebrospinal fluid turbid. The rapid, almost apoplectiform appearance of paralysis in some cases of spinal meningitis is often the cause of surprise and speculation. Of course, this may be due to toxic action on anterior roots. The sudden onset of hemiplegia in uremic poisoning is an index of how rapid may be the development of such symptoms when toxemia is the etiology. But there is another possibility in this sudden paralysis, which is supported by the experimental work of Camus and Roussy, who caused cavities within the spinal cord by the injection of a mixture of talc, sodium nucleinate and formic acid into the subarach-

noid space. This procedure caused an intense meningitis, with consequent closure of blood vessels entering the spinal cord from the pia-arachnoid. Ischemic areas of softening and cavity formation followed. Allowing, therefore, that there may be an interference of the blood supply to the lateral column of one side in the upper cervical region, it is evident that there might be an upper motor neuron hemiplegia, or possibly a perfect Brown-Séquard syndrome of rapid or apoplectiform onset.

The *toxic symptoms* in leptomeningitis are due to the action of circulating toxins or irritants in the cerebrum. The patient at first shows varying degrees of irritability even to the point of a wild delirium. Following this, as the effect of the deleterious agent becomes more profound, consciousness may become obtunded and finally deep coma may ensue. In very severe infections there may be cutaneous rashes and petechial spots. This condition obtaining in cerebrospinal meningitis gave to it the name "spotted fever."

Depending on the etiological factor, virulence of infection and method of treatment, we grade our **prognosis** from grave to hopeless. When the result of lumbar puncture is a clear fluid, arguing meningism or a serous condition, the prognosis may be guardedly favorable. But it must ever be borne in mind that the case may be in a transition period and that the next examination of cerebrospinal fluid will show turbidity. When the spinal fluid is turbid, the case must always be considered as one of extreme gravity. The use of antimeningococcic serum early in the course of epidemic cerebrospinal meningitis somewhat alters the prognosis for the better (*vide* chapter on Intraspinal Therapy, p. 795). In the parameningococcic infection there is as yet no therapy which can be depended upon to modify the course of the disease.

The **treatment** of leptomeningitis must be directed against the infection, against increased cerebrospinal fluid pressure and toward constitutional support of the patient. Except in the case of epidemic cerebrospinal meningitis, there is no specific therapy which has proved efficacious. In cases of streptococcic, staphylococcic and pneumococcic meningitis efforts have been made to combat the process by the use of the respective sera, but without very favorable results. It is always possible to relieve the increased cerebrospinal fluid pressure by lumbar puncture, unless the pus and detritus in the lower theca be so thick that it may not be aspirated. The relief of pain, both in the back and in the head, is often most gratifying following lumbar puncture, and this procedure should be instituted whenever the physical signs indicate the necessity. The flushing of the subarachnoid space with detergent or therapeutic solutions has been used and further details as to method and material will be considered in the chapter on Intraspinal Therapy. The treatment aimed to support the strength of the patient must be along general lines, special attention being paid to the emunctories as well as to the heart. Such desperately

ill cases have recovered, that it is never good policy to give up the fight until the patient has breathed his last.

SYPHILITIC MENINGITIS

Syphilis may give rise to both pachymeningitis and leptomeningitis. The vast majority of cases of syphilitic pachymeningitis are secondary to syphilitic softening of the bodies of vertebrae and what is said of tuberculous pachymeningitis applies also in this form. In fact, the differential diagnosis between these two types is not always easy. Absence of fever, history of previous syphilitic infection, lymphocytosis, examination of cerebrospinal fluid, Wassermann reaction in the blood and improvement under intensive antisyphilitic treatment are in favor of the specific **nature of the lesion.** Whether a perfected technic would often lead to the finding of *Spirochaeta pallida* in the cerebrospinal fluid and syphilitic meningitis, cannot be stated. That the organism is often present is suspected by many. Dupérié was the first to find the spirochaeta in the cerebrospinal fluid during life. Naturally, the treatment of syphilitic spinal pachymeningitis should include an intensive course of antisyphilitic therapy. But very much the more common and important variety of syphilitic spinal meningitis is the leptomeningeal form. During the past decade, a great reformation has taken place in our point of view in regard to syphilitic and the so-called parasyphilitic diseases of the nervous system. The history of the teachings concerning the etiology of tabes dorsalis and paresis is interesting, in that it demonstrates how, with constantly improving histological technic and other means at our disposal, the percentage of so-called non-syphilitic cases of tabes and paresis has gradually fallen; so that now, should one present a typical case of either of these conditions and aver non-specific origin, the burden of proof would certainly be on him. Now, microscopical examination of the spinal cord and meninges in a case of tabes dorsalis discovers more than a change in the posterior-root ganglia, and degeneration in the posterior columns. One finds practically always a small round-cell infiltration of the pia-arachnoid, with or without change in the small arteries. This may be considered a type of meningitis, and it is a question which we need not discuss here, whether the changes in the posterior-root ganglia and posterior columns are due to the presence of this small round-cell infiltration, or whether the same toxin which is responsible for the infiltration also reacts disastrously on the entering sensory fibers. Then, again, the question arises as to the genesis of the small round-cell infiltration; is it due to Spirochaeta pallida acting from a distant part of the body by means of an elaborated toxin? or to the spirochaeta present in the meninges and cerebrospinal fluid? That the latter condition has

been well proven is beyond doubt; but whether it be always the case cannot be affirmed. A logical supposition, which in time may be demonstrated a fact, is that the diseases of the nervous system that we have heretofore considered parasyphilitic and postsyphilitic are, in reality, syphilitic, and are due to the presence of the Spirochaeta pallida in the meninges and nervous tissue.

There is one important point which should be emphasized, and that is the constant finding of a small round-cell infiltration in the leptomeninges in cases of syphilis of the central nervous system. This infiltration seems to be irrespective of the blood vessel change. Of course, alteration in vessels may be a concomitant finding, such as proliferation of the intima, even to the extent of an obliterating endarteritis; but cases are frequently noted in which careful microscopical examination fails to discover any marked deviation from normal in the blood vessels, the only abnormal picture being lymphocytosis in the pia-arachnoid. Spiller has dealt with the subject of small round-cell infiltration in no uncertain terms, but he has never said that only syphilis could cause the condition. I quote the following sentence concerning lymphocytic infiltration from Spiller's paper dealing with the relation of syphilis to parasyphilitic diseases: "It is not pathognomonic, and may occur with some other conditions, but I believe there is no acute manifestation of syphilis of the cerebrospinal axis without it." There seems to me no reason for qualifying the syphilitic condition as acute, although we may go even further than this and say that there is no manifestation of syphilis either acute or chronic of the cerebrospinal axis without this lymphocytosis in the pia-arachnoid.

We must now discuss the possible **results of syphilitic involvement** of the leptomeninges. One of two eventualities may happen: first, the process may not pass beyond the condition of small round-cell infiltration, with or without arterial change. This does not necessarily mean that antisyphilitic therapy has held it in abeyance. Cases are on record where many years have elapsed and all that was found at necropsy was a lymphocytosis without marked thickening or blood vessel change. Second, with the lymphocytosis of the pia-arachnoid there seems to be an intense action whereby there is caused a great connective tissue proliferation and plastic exudate. This is so severe that the subdural space is obliterated, the arachnoidal surface of the pia-arachnoid becoming fused with the dura and the subarachnoid space greatly diminished, in places obliterated by the hyperplastic process inward. Usually, in these cases, a dense adhesion forms between the periphery of the spinal cord and the leptomeninges; the radial vessels running into the periphery of the cord take part in the hyperplasia and we find an annular zone in which the pial septa and perivascular connective tissue are greatly increased at the expense of the fiber tracts. A frequent symptom of this condition is the

syndrome of dissociated sensation, due to early involvement of an anterolateral tract. Often the sensory symptoms will precede those of the upper motor neurons by a number of months, due to the fact that the crossed pyramidal tracts lie deeper within the substance of the cord and hence are not so soon subject to the connective tissue involvement.

Symptoms. An early sign of syphilitic meningitis is *pain in the back.* This may at first be of mild character leading the physician to the unfortunate diagnosis of "rheumatism," but later on the pain becomes more insistent and of an intense and unbearable character. The cause of this pain may be twofold: it may be due to the irritation of toxins in the cerebrospinal fluid on the posterior nerve roots or it may be explained by the pressure of the small round-cell infiltration on these roots; possibly both of these explanations are correct in many cases. If the condition progresses to the stage where we have the organization of the thickened meninges with the spinal cord, it is only a question of time when we may determine alteration in sensation due to lateral column involvement. Most frequently this symptom is thermo-anesthesia and very often the earliest manifestation is a lack of ability to perceive stimuli of cold. With further progress we may find the well-defined picture of dissociation of sensibility, loss of the sense of temperature and of pain with preservation of the sense of touch. It must be realized that the inflammatory process is often unsymmetrical, particularly in the early stages of the trouble, for which reason the sensory disturbance varies on the two sides of the body. There is also usually a lack of the sharp segmental limitation seen in traumatic cases, or in tumor of the spinal cord. With continued progress, the crossed pyramidal tracts become involved and we have added to our picture the symptoms of upper motor neuron involvement, motor weakness, increased reflexes and spasticity. In severe cases there is paralysis of micturition and defecation with loss of sexual power. The sensory symptoms almost invariably precede the motor. On account of the great thickening of the meninges and the pressure which may be exerted on emerging anterior roots, the possibility of lower motor neuron paralysis must be considered. This would be most apparent in case the cervical or lumbar enlargement were involved. Naturally, in such a case the lower motor neuron symptoms would mask the upper motor neuron group, and we would find a flaccid paralysis with loss of reflexes, atrophy and electrical reactions of degeneration. Examination of the blood and of the cerebrospinal fluid, both serologically and cytologically, would be of aid in the diagnosis. Often there will be present some indication of cerebral involvement such as headache, Argyll-Robertson pupils or ocular palsies.

The **prognosis** in syphilitic spinal meningitis depends largely upon the amount of involvement of the spinal cord; with but little cord involvement the outlook is much more favorable than when myelitis is well ad-

vanced. In any case, one is never justified in giving better than a guardedly favorable prognosis, as there are cases which, even when energetically treated in their incipiency, progress despite the most radical forms of antisyphilitic therapy. Occasionally, however, when combined with a decompressive laminectomy, favorable results may be obtained.

Leptomeningitis in the upper lumbar region in a young woman, the symptoms suggesting tumor of the spinal cord. Decompressive laminectomy with progressive improvement.

The patient, a young woman, *aet.* 36 (File No. 32285), was admitted to the University Hospital, July, 1916. Her family and past medical history were not relevant to the case. She was in good health until September, 1914, at which time, being in the seventh month of pregnancy, she developed weakness of the left hip, which increased until the birth of her baby, after which event it was completely relieved. In January, 1916, she first noticed numbness and sharp, shooting pains in the left lower extremity which steadily increased in frequency and severity. By March of the same year motor weakness had developed in this limb and she was confined to bed. In June, 1916, she began to have pain in her right lower limb, at the same time developing numbness of the buttocks and inner aspects of the thighs. Two weeks later there was a slight tendency to rectal incontinence and the day before admission, July 9th, incontinence of urine developed. There was no tendency to stagger.

Physical Examination.—The upper extremities and head showed no abnormalities in neurological function. The muscles of both lower extremities were distinctly and equally wasted. She could raise the right leg easily, but the left could be flexed only very slightly at the hip and not at all at the knee. Passive flexion of the left knee caused great pain.

The sense of position and passive motion was markedly impaired in the toes of both feet. The heel to knee test showed marked ataxia on the right, but was impossible of execution on the left because of the paresis of the limb. Sensations for touch, pain, heat, cold and vibration were almost lost in the distribution of the first and second lumbar segments on the left. There were distinct hyperesthesia for these stimuli in the distribution of the twelfth thoracic and third lumbar segments. The vibratory sense was very slightly impaired over both patellae. The knee jerks were exaggerated on the right but were much decreased on the left. The Achilles jerks were prompt and equal. Ankle clonus was persistent on the right, but on the left was not always to be demonstrated. Plantar stimulation caused flexion on both sides. There was hyperesthesia in the upper part of the left leg below the knee. The sharp-cut character of the areas of sensory involvement would indicate a root rather than a cord lesion.

A positive Wassermann reaction was obtained and antisyphilitic therapy instituted. Five cubic centimeters of a clear, light green fluid were withdrawn at lumbar puncture. Within two or three minutes a white coagulum formed in the fluid (massive coagulation).

The x-ray showed an abnormal density of the first lumbar vertebra, more marked on the left, with an overgrowth of bone.

On July 10, 1916, the patient underwent a laminectomy, the spinous processes and laminae of the eleventh and twelfth thoracic and first and second lumbar vertebrae being removed. Before the dura was opened there appeared to be an enlargement beneath the laminae of the first lumbar vertebra and a constriction below this point.

Upon opening the dura there were adhesions between the arachnoid and the pia. At first it was thought that we might be dealing with an intramedullary tumor, but further inspection brought us to the conclusion that the condition was a lepto-meningitis, a lesion which would better explain the symptoms than intramedullary growth. The dural wound was closed with a continuous silk suture and the muscu-lo-aponeurotic layer with tier sutures.

Immediately after the operation the patient was relieved to a very considerable degree, if not entirely, of pain, and in the course of the next six months gained sufficient power to be able to walk about.

The fundamental principles involved in the **treatment** of syphilitic meningitis do not differ from those of syphilis elsewhere, except where intraspinal therapy may be indicated, and a discussion on this subject will be found in Chapter XIII, on Intraspinal Therapy (p. 810).

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CHAPTER X

SURGERY OF THE SPINAL ROOTS

Surgery of the spinal nerve roots is still in its infancy and the results thus far attained leave much to be desired; nevertheless few subjects in the entire field of spinal surgery at the present day are more pregnant with possibilities and more deserving of serious thought and consideration. This is not at all surprising, if one stops to consider the important rôle which the spinal roots play in the physiology of the nervous system. These thirty-one small bundles of nerve fibers, entering and leaving the cord at various levels, constitute a most important link in the great reflex arc. It is by the roots and by the roots alone that impulses from the periphery, from the muscles and connective tissues and from the organs, are conveyed to the spinal cord, whence they are conducted by neurons of the second order, some to the cerebellum and others to higher centers in the brain, where they are converted into sensations of pain, touch, temperature and the various forms of deep sensation, and it is by the roots that impulses originating in the brain and descending *via* various fiber tracts in the cord are finally conveyed from the cord to the various motor nerve fibers and then to the muscles.

The discovery that the anterior and posterior roots of the spinal nerves are respectively motor and sensory in function, made almost simultaneously by Sir Charles Bell and Magendie about a century ago, inaugurated a new era in neurology and constituted an event of far reaching importance. Since that time additions have been constantly made to our knowledge of the functions of these roots, both by experimental and by clinical methods, and these have all tended to corroborate the hypotheses of Bell and Magendie, although we now prefer to speak of the anterior and posterior roots as *efferent* and *afferent,* rather than as *motor* and *sensory,* since some impulses are conveyed *via* the posterior roots which are not sensory in the pure sense of the term. The researches of Sherrington upon the peripheral distribution of the posterior roots and of Head upon the sensory innervation of the internal organs have been of untold value in the development of surgery of the spinal roots.

Recognizing the importance of the posterior roots in the conduction of pain stimuli centralward, it was but natural that the question should arise as to the advisability of resecting the posterior spinal roots in cases of intractable pain in their distribution. The suggestion came almost simultaneously from Dana in this country and Bennett in England, and

the first two operations were performed in 1888 by Abbe and Bennett. Abbe's patient was moderately relieved for two years, when the pain returned, and Bennett's patient died on the twelfth day from a cerebral hemorrhage. The operation was soon repeated by Horsley, Chipault, Giordano, Mingazzini, Munro and others with varying degrees of success, and in 1895 Chipault outlined the technic and indications in a series of monographs, but the number of cases remained small and the results were for the most part disappointing. This may have been due to the cutting of an insufficient number of roots or, possibly, to defective technic, since the methods of identification of the individual roots were not so precise then as they are now.

In 1905, at a meeting of the New York Neurological Society, Spiller suggested that herein might lie a means of relieving athetosis, which is one of the most distressing and at the same time one of the most baffling forms of abnormal involuntary movement. The resection of the posterior roots has been carried out a number of times in cases of athetosis, but the results have been altogether unsatisfactory.

A new interest was aroused in surgery of the spinal roots in 1908 by Förster, who proposed that resection of the posterior roots be applied in the treatment of severe forms of spasticity, and described the technic which he and Tietze had carefully elaborated upon the cadaver. It was immediately put to the test by Tietze, Küttner, Guleke, Groves, Hunkin, Clark, myself and others, until now over 130 cases are on record. While the nature of the condition prohibits a complete cure, the improvement has been marked in many cases, and I advocate the operation for the relief of spasticity in the absence of the various contra-indications which I shall enumerate later. In spasticity we are dealing, as we shall see, with a condition of hypertonicity and loss of muscular balance due to a defect in the reflex inhibitory mechanism which normally maintains the tonus of the muscles. Since restoration of this inhibitory mechanism is impossible, an interruption of the reflex arc by dividing the posterior roots and thereby cutting down the afferent impulses should restore the balance, at least in part. While the results have not been all that could be desired, this does not necessarily mean that the principle is at fault, since many other factors enter into the problem, such as the proper selection and identification of roots and various other refinements in the technic.

Shortly after suggesting rhizotomy for the relief of spasticity, Förster advocated that the same method be applied in cases of visceral—particularly gastric—crises which had defied other measures, and the procedure has now been carried out many times, and has proved more successful than any of the other operative measures for the relief of this condition. Even so, however, the relief is sometimes only transitory and sometimes not so complete as one would desire.

It has been suggested by Kidd, on the ground of experimental, histological and embryological evidence, that there are afferent fibers passing to the cord *via* the *anterior* roots. If this be true, it might account for the varying results in many cases in which posterior roots have been divided for the relief of pain of various origins. Kidd believes that "we ought to divide ventral as well as dorsal roots in cases of intractable pain, except in the case of the third and fourth cervical ventral roots; here division would cause motor palsy of the diaphragm on the side of section. . . . It is, of course, true that ventral root division for pain would always cause some motor palsy, but the patient would probably almost always prefer this disability to a continuance of his pain. The fact that in some cases dorsal root division does abolish all pain suggests that it may be only in some regions of the spinal cord that any afferent fibers pass up ventral roots to their endoneural ganglionic groups of cells." Such a theory, it seems to me, requires further corroboration before we can accept it. At the present writing I am more inclined to feel that the results of rhizotomy are to be improved by a more thorough elimination of unsuitable cases, by a more careful selection and more accurate identification of the roots to be divided, and by more attention to the technical details of the operation. These problems and many others deserve our earnest consideration.

RHIZOTOMY FOR THE RELIEF OF INTRACTABLE PAIN

Owing to the fact that one of the chief functions of the posterior spinal roots is the conduction of painful sensations to the central nervous system, section of these posterior roots was first suggested for the relief of intractable pain which had defied other and less formidable procedures. At the suggestion of Dana, the first operation was performed by Abbe in December, 1888, in a case of severe, persistent neuralgia of the arm. The patient, a man 44 years of age, had suffered for two years from violent pain and spasmodic contractures in the right arm. Several peripheral operations had been performed and finally amputation of the arm near the shoulder, but all these measures failed to afford relief. As a last resort, a rhizotomy was undertaken by Abbe, who cut both motor and sensory roots of the sixth and seventh cervical nerves extradurally, and two days later performed an intradural resection of the seventh and eighth posterior cervical roots. Following the operation, there was an area of anesthesia extending from the stump to the deltoid, and across the shoulder from the center of the clavicle to the entire scapular region. For two years the patient abandoned the morphin habit and gained twenty pounds. Four years later, however, he complained of pain in the stump and a drawing sensation in the amputated fingers, although the area of

anesthesia was unaltered. His condition remained unchanged in 1910—twenty-two years after the operation. Almost simultaneously a like operation was performed in England by William H. Bennett, upon the advice of Sir Victor Horsley, for the relief of acute spasmodic pain of the left lower extremity. The third, fourth and fifth lumbar, the first and second sacral posterior roots, were cut intradurally on the left side. Relief from pain was complete after the operation, and function was being rapidly restored in the affected parts, when the patient suddenly died on the twelfth day from cerebral hemorrhage.

In addition to its indication in neuralgias of the upper and lower extremities and the intercostal region, attempts have been made to alleviate by this means the so-called amputation pains, neuritis of traumatic and syphilitic origin, pains due to herpes zoster and those due to pressure from an inoperable sarcoma or carcinoma. Rhizotomy has also been applied once in a case of erythromelalgia, and once for pain following an attack of phlebitis. Recently, the suggestion has been made that herein might be a means of treating such baffling conditions as angina pectoris (Goodall and Earle), and rebellious hyperchlorhydria (Leriche), as well as *mal perforant plantaire;* but the efficacy of rhizotomy in these latter fields is yet to be proved.

Unfortunately, the results of posterior root section for the relief of intractable pain have not fulfilled the expectations of the inceptors of the operation; and while chronologically pain is the primary indication for rhizotomy, this operation has been found to be much more effective in the treatment of spasticity and visceral crises, to which it was later extended. In a few cases to be sure, as will be seen in Table I, there has been complete freedom from pain since the operation; in others, there have been varying degrees of improvement; but in the great majority of instances the condition has been but slightly influenced. From the *a priori* arguments at hand it would seem that section of the posterior roots should be an effective means of combating peripheral pain; and it is difficult to explain why this is not more often the case. It may be, in certain instances, that too few roots or the wrong roots have been divided; yet in several cases (Ballance, Horsley, Chipault) the section of a single root was followed by complete relief. On the other hand, the failures may be due to an imperfect understanding of the nature of the pain or location of the irritation. It often happens that the original pain persists permanently after the operation despite the fact that there is complete anesthesia in the peripheral distribution of the resected roots, as in one of Grove's cases, in which the knee joint was resected without the use of an anesthetic. This must mean either that the irritation is central to the point of surgical attack, or else that pain is of a psychical rather than organic nature. Too great stress can scarcely be laid upon the importance of determining the exact nature of the pain and the seat of

the irritation before such a formidable procedure as rhizotomy is undertaken. However, in order to have a true understanding of the value of rhizotomy for the relief of intractable pain, it is necessary to consider separately the various types of pain.

Section of the Posterior Roots for Postherpetic Neuralgia

Section of the sensory roots for the relief of pain has been advocated in the neuralgias of herpes zoster. While fully cognizant of the intense suffering and of the appealing nature of these cases, we should not lose sight of the fact that with but few exceptions the neuralgia of herpes zoster is a self-limited symptom. Hence, no thought of so radical a remedy as root section should be entertained unless the pain have persisted beyond the time at which spontaneous arrest is likely. Experience tells us that in most instances the herpetic neuralgias are of comparatively short duration—a few weeks or a little longer. Occasionally the pain may persist for the greater part of a year, perhaps two years, but only in the exceptional instance will this period be exceeded.

A striking illustration of the persistence of pain in a violent, intractable form was brought to my attention in the person of a patient some sixty years of age, who had been suffering a little over two years.

A case of severe intractable pain following an attack of herpes zoster. Section of the sixth, seventh, eighth and ninth thoracic roots was followed by great relief.

The patient, male, *aet.* 60 (File No. 30825), was admitted to the University Hospital, November 1, 1915, with the following history:

December 5, 1913, while traveling in a train he was seized suddenly with intense pain in his right side. As the pain continued for the next three days he was removed in an ambulance to the hospital. An acute abdominal lesion was suspected and an exploratory operation contemplated, but the cause of the pain was revealed in the appearance of a herpes zoster. After the eruption appeared the pain was less acute but never subsided altogether. The patient remained in the hospital seven weeks and the pain was continuous and paroxysmal, requiring three doses of one-sixth grain of heroin every night for its control. Various therapeutic measures were tried, the dry electric pad, moist hot applications and other things, but without effect. The patient tried to resume his business but was able to do very little. Finsen light baths either had no effect or made him worse.

In January, 1915, he again entered another hospital, where he was under observation for eleven weeks, and while his general health improved his pain was not relieved. The question of operation was discussed but was not considered favorably.

On his admission to the University Hospital, an area of hyperesthesia was discovered in the right side extending from the spine around to the median line, from the ensiform cartilage above to the umbilicus below. At times the skin was so sensitive that he could not bear contact with his clothes. In addition to the hyperesthesia there was intense pain, varying somewhat with the weather and more or

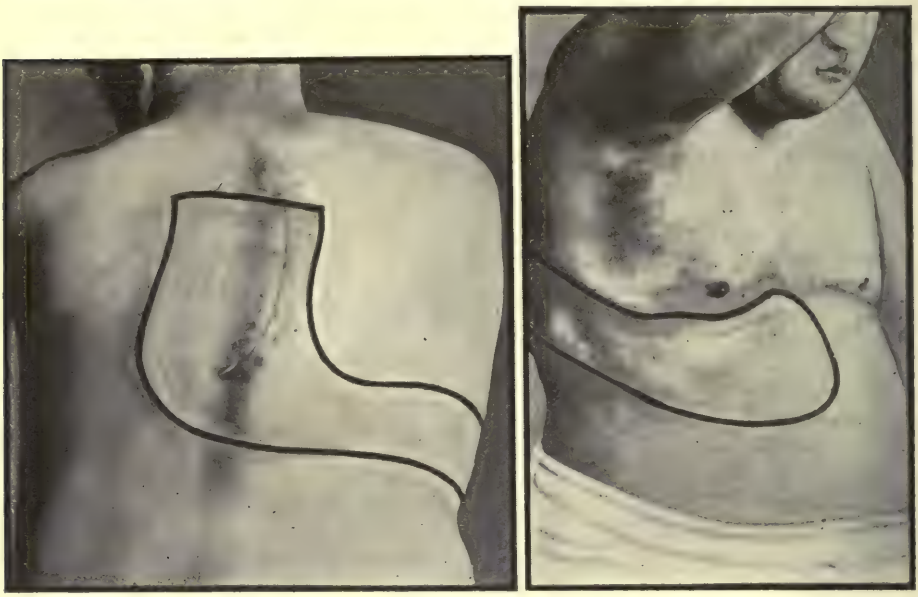
less paroxysmal in character. His physical examination revealed nothing relevant to his condition. He was seen by several neurologists, who were not disposed at the time to advise operation, but as his pain continued and from one to three grains of morphin a day were required to relieve his suffering, he pleaded for some radical means of relief. The question of an intradural rhizotomy was considered, but, before resorting to so formidable a procedure, it was decided to try the effects of alcoholic injections into the spinal root. On successive days injections were given according to our technic for injection of the ninth, eighth, seventh and sixth thoracic roots. Following injection of the eighth and ninth roots there was transitory relief, but the injections of the sixth and seventh were complete failures, at least symptomatically. The patient was discharged from the hospital with the understanding that if the pain continued with its present intensity he should return again for operation.

December 5, 1916. About a year after his discharge the patient returned to the hospital with a history of almost continuous pain since his discharge. The pain was of the same character and precisely of the same distribution. As heretofore, he required from two to three grains of morphin a day, given hypodermatically. The area of hyperesthesia, as before, extended from about the seventh thoracic spinous process above to the twelfth below; as it passed forward and downward it disappeared almost completely in the axilla, and again widened out, dumb-bell shape, until at the midline it extended from the ensiform cartilage above to the umbilicus below. In extent the area was a little less than that recorded the year before. The hyperesthesia was quite as pronounced as formerly and at times the patient suffered from this intensely.

Rhizotomy, December 13, 1916. First stage. The operation was begun under local anesthesia, but was continued under nitrous oxid-oxygen anesthesia. It was planned to remove the laminae and spinous processes of the fourth, fifth, sixth and seventh thoracic vertebrae. After three laminae and spinous processes had been removed, namely, those of the fifth, sixth and seventh thoracic vertebrae, the patient's pulse became rather feeble, his heart action weak, and it was deemed wise to postpone further procedure until a second operation.

Rhizotomy, December 19, 1916. Second stage. Under ether anesthesia the original wound was reopened, one more arch above and below the opening was removed, and the dura opened, the cerebrospinal fluid discharging as though under considerable tension. According to our revised technic, preliminary to the division of the roots a fine ligature of arterial silk was tied about each root distal to the point of division. Beginning with the sixth, the four successive thoracic roots were divided, and after their division there was absolutely no oozing. This degree of perfect hemostasis was attributed to the ligature, which included not only the root but the small artery which accompanies it. At the conclusion of the operation the patient was given one c.c. of pituitrin and fifteen minims of camphorated oil. The pulse rate was 108 and his general condition satisfactory. From the day after the operation and for the next twelve successive days the patient received gradually diminished doses of morphin hypodermatically until, on December 29th, he received only one-third of a grain and from that day on none. An examination of the distribution of the sixth, seventh, eighth and ninth roots revealed an area of complete anesthesia practically corresponding to the zone of hyperesthesia before the operation (Figs. 262 and 263). His convalescence was uninterrupted and he was discharged from the hospital three and one-half weeks after the operation entirely free from pain and wholly independent of morphin. The results, on the whole, were extremely gratifying to the patient and more than justified the undertaking.

General Considerations.—Clinical experiences have been so infrequent that I venture to open a discussion of this topic upon a purely hypothetical basis. The question before us is: have we grounds, clinical or pathological, for belief in the possibility of relieving intercostal neuralgia of herpetic origin by an operation which blocks the sensory impulses proximal to the spinal ganglion? The very first inquiry that presents itself concerns the pathology of herpes zoster: is the lesion central



FIGS. 262 AND 263.—THE ZONE OF HYPERESTHESIA BEFORE AND ANESTHESIA AFTER OPERATION IN CASE OF POSTHERPETIC NEURALGIA. (Posterior and anterior views.)

These illustrations are of further interest as showing the territorial distribution of the cutaneous rami from the posterior primary divisions of the spinal nerves. From the effect of trauma or overstretching, perhaps division in the course of the laminectomy, the function of these nerves has been abolished, so that there is an area of anesthesia 4 or 5 cm. on either side of the spinal column. This is the anesthesia which should be procured by the injection of the intercostal nerves according to the technic of regional anesthesia. (See page 880.)

or peripheral? does it involve primarily the peripheral nerve or the ganglion? is the cord secondarily involved? and is the lesion ever centrad to the ganglion? Consensus of opinion stamps the true, clear-cut herpes zoster as a disease of infectious origin—exceptions to be made, of course, in those cases where traumatism, the irritation of tumors, myelitis or tabes may play a part.

According to Bärensprung, the pathological process may be found in the ganglion; others have found a peripheral neuritis as the fundamental cause, as Dubler who proved not only that the peripheral nerves were involved but also that the ganglia were not involved. As a result of most painstaking pathological and histological investigations in 21 cases of

herpes which came to autopsy, Head and Campbell demonstrated that the fundamental pathological lesion in primary spontaneous herpes is an acute, often hemorrhagic, inflammation of the ganglia, the changes consisting of (1) an extremely acute inflammation with the exudation of small, round, deeply-staining cells; (2) extravasation of blood; (3) destruction of ganglion cells and fibers; (4) inflammation of the sheath of the ganglion. These authors concluded, moreover, that not only were the spinal ganglia most commonly affected, but the causative agent, whatever its nature, showed an affinity for those particular ganglia which received afferent impulses from the viscera and in which the small cells predominated. Thus, herpes was found to involve the second, third and fourth cervical ganglia and the third thoracic to the first lumbar ganglia more often than the others. In the mild cases, resolution takes place without any permanent changes in the ganglionic structure, but in the severe cases a terminal sclerotic process develops which in time leads to a secondary degeneration in the spinal cord, the posterior roots and the peripheral nerves. Involvement of the cord has been reported by Bruce, Besche and others; in a case reported by Thomas-Laninière there were hemorrhagic foci in the gray substance of the lateral horns, also degeneration of the rami communicantes. The lymphocytosis which is noted in many cases of herpes also points to cord involvement. The disease was found by Head to be so completely analogous in both its clinical and its pathological manifestations to acute anterior poliomyelitis that he goes so far as to say that herpes zoster "might justly be spoken of as an acute posterior poliomyelitis," particularly since the posterior root ganglion is the exact equivalent of the anterior horn.

This brief pathological review answers our inquiry as to the seat and nature of the process. In the acute stage, the primary lesion is in the ganglion; in the terminal stage, secondary sclerotic processes may involve the nerves, peripheral to the ganglion, the sensory roots, or in exceptional cases even the cord itself. Upon this pathological basis and upon purely hypothetical grounds posterior root section should be as effective in relieving the pain of postherpetic neuralgia as it is in affording relief to the pain of tabetic crises or trigeminal neuralgia, but unfortunately this hypothesis has not been borne out by the few cases on record, so that the wisdom of operating under any circumstances must be considered *sub judice*.

Thus far there have appeared in literature the records of but four operations, to which should be added the case I have just recorded, and of these there was one recovery, two cases with and one without improvement, and one operative death (Table I, p. 638). In a case operated upon by Ballance only the first thoracic posterior root on the left side was divided. The pain and hyperesthesia disappeared and there was no re-

currence during an interval of some years following the operation. In Kolb's case in which the sixth, seventh and eighth thoracic roots were cut, the patient is reported to have improved, but no time is given. Barling resected the second and third thoracic roots on the left side, in a case of postherpetic neuralgia of the left shoulder, pectoral region and axilla; immediately after the operation the pain entirely subsided, but on the eighth day it reappeared and gradually became as severe as ever. In

FIG. 264.—A SCHEMATIC SKETCH OF THE SPINE TO SHOW THE POINTS OF INJECTION OF THE SPINAL NERVES FOR REGIONAL ANESTHESIA.
The vertical lines are 2.9 cm. from the median line, the horizontal lines pass through the spaces between the transverse processes.

Thomson's case the posterior roots on the left side from the sixth cervical to the second thoracic were resected for neuritis, following an attack of herpes five months before, but the patient did not rally and died forty-eight hours after the operation. In my case the sixth, seventh, eighth and ninth roots were divided for the relief of postherpetic neuralgia with striking effect.

Leaving out of consideration for the time being operative intervention,

let us consider **alcoholic injection** of the roots. Its performance must be left to those who are familiar with the difficulties and risks; the technic is harder to master than that of alcoholic injection for trigeminal neuralgia, chiefly because of the variability of the anatomical landmarks. It is not always easy to define on the skin surface the exact position of the spinous processes of the individual vertebrae, and the relation of these spinous processes, which serve as our landmarks, to the intercostal foram-

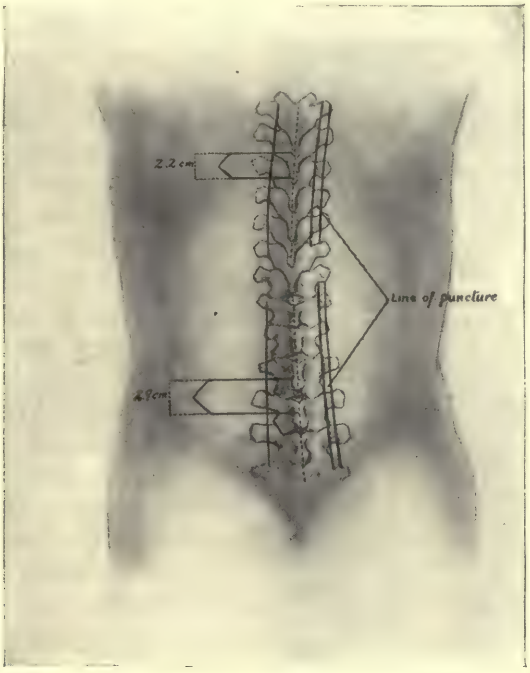


FIG. 265.—SCHEMATIC SKETCH OF THE THORACIC AND LUMBAR SPINE, INDICATING THE DISTANCES BETWEEN THE TRANSVERSE PROCESSES IN THESE TWO REGIONS.

The vertical lines are 2.9 cm. from the midline. The distance between the midpoints of the spaces between the transverse processes in the thoracic region is 2.2 cm. and in the lumbar region 2.9 cm.

ina varies according to whether we are working in the cervical, thoracic or lumbar regions.

The problem of subcutaneous injection of the spinal roots was made a subject of investigation by a member of my staff, Dr. W. A. Sawyer, for which purpose he employed the human cadaver and animal experimentation. He found in the first place that it was comparatively simple to come close enough to the nerve to inject the alcohol immediately around it and this would suffice for the purpose of obtaining a transitory anesthesia. But to introduce the needle so that it would actually pierce the root whereby the alcohol could be injected directly into the substance

was a very much more difficult problem. The technic was elaborated only with reference to the thoracic roots. Apart from the anatomical studies as to the most accurate method of penetrating the root, an inquiry was made into the possibility of the alcohol entering the dural sac or the spinal cord. For this purpose an alcohol solution colored with methylene blue was injected with a hypodermic needle directly into the root, but on no occasion was any of the stained fluid found either within the sac or within the cord so that the likelihood of permanent danger to the cord seemed remote.

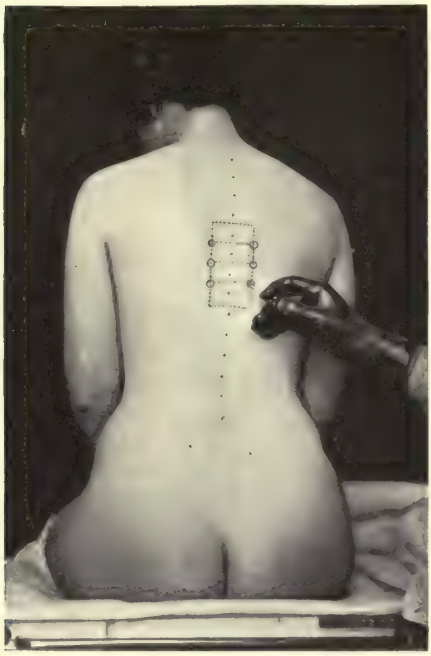


Fig. 266.—Points of Injection of the Intercostal Nerves. (Compare with Figs. 264 and 265.)

To ensure accuracy it is, of course, necessary that the patient be conscious. As in alcoholic injection of the trigeminal nerve, one must depend upon the patient's coöperation to determine whether the needle is actually in the substance of the nerve. If a number of intercostal nerves or roots have to be injected at one operation, manifestly the ordeal would be more than the patient could be expected to endure. Hence an attempt was made to devise a means whereby the exact location of the needle could be determined with the patient under an anesthetic. After discussing many methods, the idea of electrical localization was conceived and applied in the laboratory experiment. When the needle was in contact with the root there was always a contraction in the muscles which that root supplied. If the electrode were not in actual contact, but merely adjacent to it, perhaps a millimeter or two distant, there was no reaction, provided a minimum current were used. The experiment proved that the current can be so controlled that a reaction follows only when the tip of the electrode is in actual contact with the spinal nerve root. This guide has not been applied to the human subject, but is offered as a suggestion. For its performance an electrode should be procured completely insulated except at its tip, which should project just beyond the end of a lumbar puncture needle.

After numerous observations there was no doubt in the mind of Sawyer that attempts at injection of the spinal roots should not be undertaken without practice on the cadaver. Only by this can the operator

become sufficiently familiar with the anatomical variations and relationships to justify the expectation of a successful injection.

The following are the directions for injecting the thoracic roots based upon the above experiences: The position of the spinous processes is first determined by palpation and marked with an aniline pencil; 2.9 cm. to the right or left of this point a line is drawn parallel to the spinal column. At a point on a level with the center of the space between the transverse processes, a horizontal line is drawn at right angles with the above mentioned vertical line. The intersection of these two lines is the point at which the needle is introduced (Fig. 264). The measurements must be made as accurately as possible, for if the needle be introduced at a point more than 2.9 cm. from the midline, there is danger, because of the angle at which the needle might be held, of entering the spinal canal through the intervertebral foramen and injuring the spinal cord.

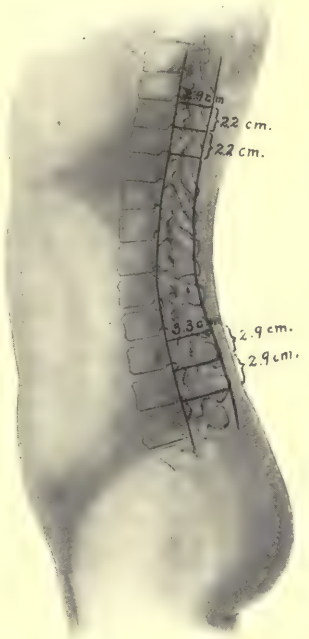


Fig. 267.—Lateral View of the Vertebral Column to Show the Distance from the Spinous Processes to the Intervertebral Foramina and the Distances between the Intervertebral Foramina in the Thoracic and Lumbar Regions. (After Allen.)

It is not always easy to find the space between the transverse processes. Approximately they are on a level in the thoracic region with the tips of the spinous processes. This localization should be confirmed by an attempt to feel the intertransverse space. After one intertransverse space has been localized by this method, the others may be found more easily, since the distance between the intertransverse spaces in the upper thoracic region is 2.2 cm. and in the lower thoracic and lumbar regions 2.9 cm. (Fig. 265).

If the needle be inserted at an angle with the transverse line of less than 45 degrees the needle may pass through the intervertebral foramen and on into the cord substance. On the other hand, if the needle be directed at an angle of precisely 45 degrees or a little larger, the danger is averted (Fig. 266). As an additional guide the needle should be directed at an angle of 35.5 degrees to the cutaneous surface. This can be readily measured with a protractor. The intervertebral foramen should be reached at a distance of about 3 cm. in the upper thoracic and 4 cm. in the lower thoracic region, and in stout individuals a centimeter, a little more or less, must be added (Fig. 267). If more than one thoracic root is to be injected in order to reach the root above or below the first injected, the

needle is introduced at a distance of 2.5 cm. from the primary point of injection. That is to say, the distance from the midpoint of one interspace between the transverse processes to another is about 2.5 cm. The pain of the injection may be controlled somewhat by first injecting 0.5 per cent novocain. Not more than 1 c.c. of 80 per cent alcohol should be injected in each root.

TABLE I

SECTION OF POSTERIOR ROOTS FOR THE RELIEF OF PAIN

	Recovered	Greatly Improved	Improved	Unimproved	Operative Death	Later Death		Total
						Improved until Death	Unimproved until Death	
Brachial plexus neuralgia	2	2	..	1	..	..	..	5
Intercostal neuralgia	..	..	..	..	2	..	1	3
Sciatica	..	..	1	1	..	..	..	2
Postherpetic neuralgia	1	..	2	1	1	..	..	5
Syphilitic neuralgia	..	..	..	1	3	1	..	5
Traumatic amputation pains	2	1	..	1	1	1	..	6
Rupture brachial plexus	..	..	1	1	..	..	..	2
Other injuries	2	1	..	..	..	..	1	4
Malignancy	..	..	1	2	1	6	2	12
Miscellaneous erythromelalgia	..	1	..	..	..	..	..	1
Phlebitis	..	..	..	1	..	..	..	1
Tuberculosis	..	1	..	..	..	..	..	1
Infantile hemiplegia	..	..	..	..	..	1	..	1
Cerebrospinal meningitis	..	..	..	1	..	..	..	1
Congenital origin	..	1	..	..	..	..	..	1
TOTAL	7	7	5	10	8	9	4	50

SECTION OF THE POSTERIOR ROOTS FOR BRACHIAL PLEXUS NEURALGIA, INTERCOSTAL NEURALGIA AND SCIATICA

Posterior root section has been practiced for the relief of other neuralgias, particularly intercostal, brachial and sciatic. Syphilitic neuralgias might have been included, as there are five cases of these in our table, but there are many reasons, irrespective of the miserable showing of surgical therapy, why operative treatment is inappropriate in these.

Intercostal neuralgia and so-called brachial neuralgia are, except for their distribution, very much akin. In the expression and character of the pain and in their etiology, so often vague, these two forms of neuralgia may be properly considered together. A glance at the table (Table I, above) will show what has been accomplished by root resection, and for

the time being I merely give a brief résumé of the few cases thus far on record. Although I have resected roots for the relief of pain, where the pathology is more definite, as in malignancy and trauma, I have never seen a case of intercostal or brachial neuralgia where I have felt justified in recommending operation, nor, on purely theoretical grounds, am I prepared to recommend it. These remarks apply with equal force to sciatica, where, because of the greater difficulty in reaching the roots of the lumbosacral cord, the operation is a more formidable procedure.

EPITOME OF CASES

Neuralgia of the Brachial Plexus

Case I.—Operator, Abbe. The patient had suffered from severe pain occurring in spasms for a period of three years. Several successive peripheral operations, stretching and resection of the ulnar nerve and stretching the brachial plexus in the axilla, had been performed without success. In 1889, Abbe resected the posterior roots of the sixth, seventh and eighth cervical and first thoracic segments. Two months after the operation there was complete anesthesia of the left hand up to two and one-half centimeters above the wrist and over the entire dorsum of the upper arm half way above the elbow to the shoulder. There was some improvement. In his report Abbe states "the patient never requires anodynes, and his physician thinks that much of what he still calls pain is a memory sense."

Case 2.—Operator, Chipault. The patient had been suffering from intense brachial neuralgia of long standing. Intradural resection of the posterior root of the eighth cervical segment was followed by complete freedom from pain two and one-half years after the operation.

Case 3.—Operator, Chipault. The patient, a man 42 years of age, had suffered from paroxysmal pain in the arm for fifteen years, for the relief of which his forearm, and later his upper arm, had been amputated, and the nerves of the stump resected. In December, 1897, Chipault resected the eighth cervical and first and second thoracic posterior roots. There was no return of pain three months after the operation, but the patient continued to be hysterical and addicted to morphin.

Case 4.—Operator, Jones. The patient, a man 50 years of age, had suffered for sixteen years from shooting pains in his right forearm, involving the shoulder and extending into the dorsal side of the head of the radius, being most pronounced along the thenar eminence and the lower attachment of the deltoid. In 1908 the large connecting trunk between the fifth and sixth cervical nerves was sectioned in the neck. But the pain returned and in 1909 Jones resected the posterior roots of the fifth, sixth and seventh cervical nerves. There was no improvement after the operation.

Case 5.—Operator, C. H. Mayo. The same patient (Case 4) was later operated upon by Dr. C. H. Mayo, who resected the posterior roots of the fourth and eighth cervical segments in 1909. In 1911, the patient wrote that he had been relieved of pain, but that his right leg had never regained its power, and there was lack of sensation in the toes of the right foot. The right shoulder and arm were also numb.

Intercostal Neuralgia

Case 1.—Operator, Chipault. The patient had suffered from excruciating pain in the back and side for four years. Chipault resected the posterior roots of the fifth, sixth and seventh cervical nerves. There was no improvement, and the patient remained in coma until his death on the third day.

Case 2.—Operator, McCosh (Quoted by Abbe). For severe intercostal neuralgia McCosh resected the posterior roots of the fifth and sixth thoracic segments, but there was no improvement after the operation. The patient died of tuberculosis a year or so later.

Case 3.—Operator, Horsley. The patient, a man 33 years of age, suffered from severe pain in the distribution of the eighth and ninth thoracic roots. At the operation, Horsley resected the posterior roots of the eighth and ninth thoracic segments, but no further data are given.

Sciatica

Case 1.—Operator, Giordano. The patient, a man 26 years of age, had suffered for some time from violent sciatica and had undergone stretching of the sciatic nerve without improvement. Giordano resected the eleventh and twelfth thoracic and first lumbar posterior roots. This was followed by great relief. Immediately after the operation there was complete loss of sensation in the lower extremity and seven months later pain sense and tactile sense had returned.

Case 2.—Operator, Hildebrand. The patient, a man 60 years of age, had been suffering for nine months from a severe pain in the right lower extremity. Hildebrand resected the posterior roots of the first to the fifth lumbar nerves on the right side. This was followed by no improvement one month after the operation.

Section of Posterior Roots for Amputation Pains

The intractable pain that follows amputations, chiefly of the lower extremities, would seem at first thought to offer an indication for root section. Stump neuralgias have been attributed to involvement of the nerves in scar tissue, neuroma formation or ascending degeneration. Neuralgia of the stump is not a neuralgia in the true sense of the word, but has a definite pathological basis. According to Weir Mitchell, these neuralgias never exist without a definite lesion of the nerves, usually an ascending sclerosis, so that the various procedures dealing with the stump alone, such as excision of the scar and of neuromata, re-amputations and the resection of nerve trunks usually prove to be ineffective. In many cases the situation is complicated by the existence of traumatic neurasthenia. This has been attributed to the shock of the accident and introduces an element of doubt as to the true nature of the lesion and the intensity of pain. As an illustration of intractable stump neuralgia the following case which I was called to see some time after the injury may be cited:

Excruciating pains following amputation of the two lower extremities and the right arm in a man 43 years of age who had been thrown from a moving train.

The patient, a man, *aet.* 43, in July, 1912, when attempting to board a moving train, was thrown under the wheels. It was found necessary to amputate the left arm above the elbow, the right leg midway to the ankle, and the left leg just above the ankle. Two months after the operation patient began to have pain in his left arm referred, first vaguely to the hand, later to the index finger and then to the back of the hand. This condition persisted without any change except that the pain became gradually worse until March, 1913, when the scar of the stump on the left arm was excised and the stump of the median nerve resected. The pain, however, became steadily worse, was constant day and night, and was described as "a hot iron drawn across the hand." Alcoholic injections at the tender point on the inner aspect of the arm failed to give relief.

When author saw the patient in September, 1913, the following notes were made:

Upper Extremities.—Examination of arm fails to reveal anything except small areas of hyperesthesia here and there about the size of a penny. There is still one point of tenderness above that where alcohol was injected. Pressure on this spot causes tingling in the thumb.

Lower Extremities.—Ever since the wound healed he has had a tender spot on the stump of each leg. The point is about five centimeters above the level of the stump, between tibia and fibula but nearer the fibula. These, however, did not interfere in any way with the use of his artificial limbs. About the beginning of July the stumps began to get sore, first the right and then the left, beginning on the right leg at the inner aspect of the stump, about one and one-half centimeters above the scar, and extending up seven and one-half centimeters just anterior to the flexor group of muscles. The stump, however, is sore all over. The whole stump of the left leg is also sore, but the pain is more intense along the space between the tibia and fibula for a distance of seven and one-half centimeters above the level of the stump. The original points of tenderness in both stumps still persist. Both are subject to sensations of chilliness and heat; when in dependent posture, they are cold; in horizontal posture, flushed; and they are uncomfortably warm in the morning.

The pain in the left leg is entirely different from that of the arms. It is not constant, there is no regularity in the attacks, and no factors seem to influence it. Patient describes the pain as hot and burning in character in the legs, as in the arm, but there is this difference, that in the upper extremity his pain is referred to the hand, while in the lower extremities to the stumps. He has never felt as though he had feet since the accident. He can handle the stump of the arm freely at any time without discomfort, but when his legs are sore he cannot touch them. The pain never extends above the knee in the lower extremities and is not referred above the shoulder in the upper extremity.

Five years have elapsed since the accident. The patient is a confirmed invalid and the painful sensations continue uninfluenced by time or treatment.

Upon a purely theoretical basis the surgeon may feel justified in recommending this operation. The pain is intractable, the suffering intense, the patient demoralized and the lesion, an ascending neuritis, begins in the stump and does not involve the cord. Hence the division of a suf-

ficient number of posterior roots should meet the indications. But a glance at the epitome in the six clinical cases is not convincing (Table I). To be sure there were two cases of complete relief, but the periods—three weeks and three months respectively—are not long enough to be admitted as conclusive evidence. A fair example of the futility of the operation is seen in a case of amputation of the arm, operated upon by Munro and reported by Knapp, in which the fifth, sixth, seventh and eighth cervical and first thoracic posterior roots were divided. Two years later the patient complained of as much pain as ever, and in spite of the division of so many roots the sensibility of the stump was the same as before the operation.

EPITOME OF CASES

Case 1.—Operator, Burrell. (Reported by Knapp.) The patient, a man 40 years of age, began to have severe pain less than fourteen months after the amputation of the left leg seven and one-half centimeters below the knee; the pain was distributed to the stump, foot and ankle. In February, 1892, the scar was excised, and in April, 1896, an intradural section of the roots to the sciatic plexus was performed on the left side. The patient died on the operating table at the end of the operation.

Case 2.—Operator, Munro. (Reported by Knapp.) The patient, a man 25 years of age, began to have severe pain in the stump immediately after the amputation of his right forearm in 1898. Neuromata were removed and in 1901 an amputation above the elbow was performed, but there was no relief, and in February, 1902, the sixth, seventh and eighth cervical and first thoracic posterior roots were divided intradurally on the right side. There was no improvement in 1904. The pain in the stump was still severe and spastic paraplegia was so marked that the patient had lost voluntary power in the legs.

Case 3.—Operator, Kiliani. (Reported by Jacoby.) The patient, a man 37 years of age, began to have severe pain almost immediately after amputation of the right forearm. The pain was distributed to the stump and missing hand; bulbs were removed several times from the nerve ends. In 1906, the pain was so severe that Kiliani resected the posterior roots of the fifth, sixth, seventh and eighth cervical and first thoracic segments. Three months later the pain had disappeared, although there was soreness in the shoulder and stump.

Case 4.—Operator, Bennett. The patient, who had had his arm amputated after an injury the year before, had been suffering from extreme pain and clonic movements in the stump. The bulbous nerve endings were removed but to no avail. In March, 1908, Bennett divided the posterior roots from the fifth cervical to the first thoracic on the right side. This was followed by relief of pain. The time is not stated.

Case 5.—Operator, Kilvington. The patient, a man 21 years of age, had had his arm amputated about ten years before the operation, and since that time had complained continuously of pain referred to the inner side of the wrist and inner three fingers. The peripheral nerves in the stump had been divided several times but without success. In April, 1914, Kilvington divided the nerve roots as they

pass out in their own dural sheaths central to the posterior root ganglia. Ten weeks after the operation there had been no return of pain.

Case 6.—Operator, Rowlands. The patient, a man 50 years of age, suffered from severe pain in the stump of the left arm, the result of an amputation five years before. Several peripheral operations had been performed without success. In 1900 Rowlands removed the posterior root ganglia of the fifth, sixth, seventh and eighth cervical and first thoracic nerves. The stump was insensitive after the operation, but the patient died in three weeks from cerebral hemorrhage.

Section of the Posterior Roots for the Pain of Malignant Disease

In the exhausting and agonizing root pains of malignant lesions of the spine or spinal cord there seems to me a greater justification for the attempt to ameliorate the condition by section of the roots. Another positive indication is the insufferable pain of malignant infiltration of the cords of the brachial plexus secondary to carcinoma of the mammary gland. I have operated for each of these conditions and while in neither case was the pain altogether relieved, it was so substantially alleviated that I would have no hesitancy in resorting to the operation under similar circumstances. Of the twelve cases we have found in literature the primary lesion in eleven was a carcinoma of the breast with secondary involvement of the axillary or cervical lymph nodes in five, and of the vertebrae in six (Table I, p. 638).

Section of the Posterior Roots for the Relief of Pain of Traumatic Origin

While pain is not always a conspicuous feature in cases of avulsion or rupture of the brachial plexus, it is severe enough in some instances to demand radical measures. My attention was directed to this condition by the following case:

Severe pain and hyperesthesia following rupture of the brachial plexus in a man 43 years of age. At the operation it was found that the anterior and posterior roots of the sixth, seventh and eighth cervical nerves were absent. The fifth cervical and first thoracic roots were divided. While a little pain still persisted, the patient's general condition was much improved and he was able to resume his occupation.

The patient, a man, *aet.* 43, was admitted to my service at the University Hospital, May 10, 1910 (File No. 6639). On Feb. 14, 1910, while walking along the street, the patient was struck on the left shoulder and head and crushed to the ground by a man falling from the fourth story of a building. After recovering from the shock of the accident, it became evident that he had sustained an injury to the brachial plexus. There was complete anesthesia for pain, touch, heat and cold, up to the elbow, hyperesthesia for a distance of seven and one-half centimeters

above the elbow and hyperalgesia in the shoulder, neck and upper chest. There was complete paralysis of all the muscles of the left upper extremity, including the deltoid and the pectoralis major and minor, and some weakness of the sternocleidomastoid. The rhomboidei, levator anguli scapulae, and the serratus magnus were not involved. The reflexes of the upper extremity were altogether abolished, those of the lower extremity exaggerated. The oculopupillary phenomena, contraction of the pupil and exophthalmos, indicated an injury to the ciliospinal fibers of the sym-

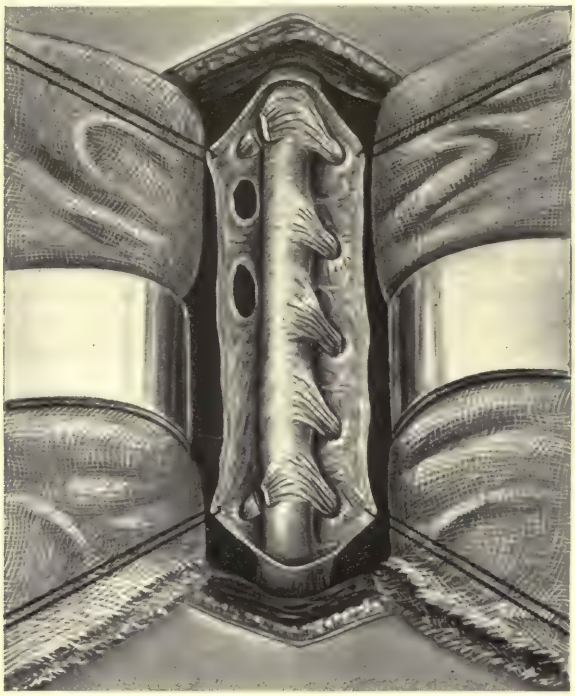


FIG. 268.—DRAWING SHOWING THE FINDINGS AT OPERATION IN A CASE OF AVULSION OF THE BRACHIAL PLEXUS.

Note the two defects in the dura and the absence of the spinal roots, the sixth, seventh and eighth cervical.

pathetic. There was some evidence of injury to the seventh cervical and first thoracic vertebrae. The symptom-complex indicated an involvement of structures supplied by the sixth, seventh and eighth cervical nerves, with impairment of function or irritation of the fourth and fifth cervical and the second thoracic. In addition to this, however, there was some hyperesthesia of the cervical plexus (C_1, C_2, C_3). There were also some functional disturbances of the left lower limb.

The utter demoralization of the patient, his dependence upon morphin, the definite evidence of a plexus lesion and the acknowledged hopelessness of any other kinds of treatment formed a justification for resort to radical measures.

Operation.—May 23, 1910, under nitrous oxid-ether anesthesia, preceded by a hypodermic of morphin and atropin, with the patient in the reversed Trendelenburg position and on his side, a curved incision was made through the skin and down to the aponeurosis, beginning at the spinous process of the fourth cervical and extending to the spinous process of the second thoracic vertebra. On reflec-

tion of the cutaneous flap, a linear incision was made in the aponeurosis in the median line, the muscles separated from the spinous processes of the fifth cervical to the first thoracic vertebrae, which, together with the laminae of the sixth and seventh, were removed. On opening the dural sac the cerebrospinal fluid was found to be under considerable tension and about one and one-half to two ounces immediately escaped. Inspection revealed the following conditions: On the left lateral aspect of the canal corresponding to the level of the sixth cervical and the first thoracic vertebrae there were two defects in the dura, each as large as a ten cent piece. On the left side both the anterior and posterior roots of the sixth, seventh and eighth cervical nerves were absent (Fig. 268). The roots evidently had been torn completely from the cord. There were some adhesions between the cord and dura on the posterior surface at the level of the seventh cervical and first thoracic vertebrae. These may have been the site of subdural hemorrhage at the time of the accident. The operation was undertaken with the intention of carrying out a purely palliative procedure. We planned to cut the posterior roots of the fifth, sixth, seventh and eighth cervical and the first thoracic nerves. As the sixth, seventh and eighth were absent and I had just divided the first thoracic, it remained only to divide the fifth cervical. The latter was reached by removing only one lamina of the fifth cervical vertebra. The dural incision was closed with continuous catgut sutures, the muscles with interrupted and the aponeurosis with a continuous catgut suture. A stab wound was made for the introduction of a small cigarette drain and the cutaneous wound closed with a continuous silk suture.

June 20, 1910, twenty-seven days after the operation, the patient left the hospital. In the interval between the operation and his discharge the amount of opium was gradually reduced until for a few days he was able to pass both the day and night in a reasonable comfort with none at all—a condition which had not existed since the time of his injury three months before. He still had many of the subjective sensations in the arm, including pain of which he had complained before the operation, but the pain was more bearable and the burning sensation or hyperalgesia in the distribution of the fourth cervical and second thoracic had in a large measure disappeared. He had the reflex pain excited in the arm by stroking the hyperalgesic area on the chest. The general morale of the patient was in slight measure improved, so that he was able in the fall of 1910 to resume his business to a limited extent.

In addition to the various sources of pain already considered, malignancy, traumatism and certain neuralgias, resection of the roots has been undertaken in isolated instances for erythromelalgia, phlebitis, tuberculosis, infantile hemiplegia and the pain following cerebrospinal meningitis. There seems to the author in these conditions nothing that commends itself as a justification for so formidable an operation.

RHIZOTOMY FOR THE RELIEF OF SPASTICITY

Attention was directed anew to section of the posterior spinal roots when, in 1908, Förster conceived the idea of treating spasticity in this manner and elaborated a technic for the purpose. A number of

operations were at once performed for him by Tietze and Küttner, who added various refinements, and the results following rhizotomy in this field promised at least a measure of relief. Between the years 1908 and 1916 we have been able to collect 132 cases of spasticity reported in detail in which the posterior roots have been divided. In 4 cases the spasticity was practically cured, in 50 greatly improved, in 47 improved, while 11 were unimproved. There were 14 operative deaths, and 6 patients died some time after operation from various causes. This series of cases includes Little's disease, infantile spasticities of various types, spastic spinal paralysis and the spasticities associated with multiple sclerosis, spinal trauma, tumors and Pott's disease. Although the number of complete recoveries must necessarily be small on account of the nature of the underlying pathologic processes, nevertheless, so large a percentage of improvements commends for the operation at least an unbiased consideration.

Spasticity, as Förster conceived it, is caused by pathological changes at some point along the corticospinal pathway. The inhibitory fibers, controlling and checking the sensory stimuli, which enter the gray substance of the cord through the posterior roots, are thus damaged and as a result the "sensory afflux acts unrestrained upon the muscles, thus causing the spastic symptoms." The mixture of reflex inhibitory fibers with pure upper motor neuron fibers, so far as we know, is so complete that it would be impossible to injure the one without injuring the other, and the clinical proof of this is demonstrated by a careful examination of spastic cases in which some diminution in motor power is almost always found.[1] It is quite evident that by resecting the posterior roots the sensory impulses would be reduced, and as a result we should have a diminution or disappearance of the spasticity. It should be constantly borne in mind, however, that there may be a paresis or paralysis which is hidden by the spastic symptoms. If the fibers carrying the motor impulses have been seriously damaged, rhizotomy should never be resorted to, as a complete paralysis would necessarily remain after the removal of the spastic symptoms. Therefore, in all cases where there is the slightest doubt, the stovain test, as advocated by Goldscheider and others, should be applied (*see* p. 666).

Too great emphasis can scarcely be laid upon the need of careful and persistent after-treatment. Even in cases where voluntary motion is not seriously impaired, normal movements will be possible only after much exercise and training. Thus, cases of Little's disease and infantile spasticity, in which the intellect is defective, should be excluded. Little is to be expected, moreover, from rhizotomy, unless the lesion causing the spasticity be stationary or very slowly progressive. But in order to understand the indications and contra-indications more fully, it will be

[1] For a more complete description of the physiology of spasticity, *see* p. 119.

necessary to review the various pathological conditions in which spasticity is the predominant feature.

Congenital Spastic Paraplegia and Diplegia (Little's Disease)

Of the various spastic affections of the central nervous system, spastic paraplegia and diplegia of congenital origin, so-called Little's disease, may yield most promptly and most favorably to the influence of rhizotomy. Herein, it seems to me, lies a most promising field for section of the posterior roots. While here, as in other varieties of spasticity of organic origin, the fundamental pathological lesion or developmental defect prohibits a complete cure in the majority of instances, nevertheless, the improvement in many cases has been so marked, and the condition to be relieved so distressing, that I feel justified in recommending rhizotomy in all cases of congenital spastic paraplegia and diplegia which do not present any of the contra-indications to be enumerated later (*see* p. 666). The various orthopedic procedures upon tendons, muscles, or bones have been but attempts to treat symptomatically the end results rather than to reach the source of the trouble. Rhizotomy is an attempt to accomplish the latter; and in certain of the less severe and more circumscribed cases, Stoffel's peripheral resection of the fibers supplying the hypertonic muscles also may prove to have some merit.

We have been able to collect 70 cases of Little's disease in which a rhizotomy has been performed since Förster's proposal in 1908. Of these there have been 2 practically cured, 56 improvements, 3 unimproved, and 9 deaths—a mortality of 12.8 per cent (Table II, p. 676). In order that we may estimate the effectiveness of the operation, for this condition, a painstaking analysis of the end results is imperative, as well as a careful study of the etiological factors, the pathological lesions and their clinical manifestations. It is only in this way that we may finally determine in which cases rhizotomy may be beneficial.

There has been in the past a great deal of confusion as to the classification and nomenclature of congenital and infantile spastic affections, and even to-day there is not complete concurrence of opinion. This is to be attributed principally to the fact that there is no single etiological factor; indeed, as Déjerine so well expresses it, the so-called Little's disease is in reality not a disease at all, but rather a syndrome. We are here dealing with a very heterogeneous group of conditions when viewed from an etiological or pathological standpoint, but with a very similar group of cases when their clinical aspects are considered. This naturally tends to complicate a complete understanding of the affection and adds difficulties to the problem of finding a proper form of treatment. Most authors have applied the term *spastic paraplegia* to bilateral cases of spinal origin, while *diplegia* has been largely confined to bilateral cases with a fundamental

cerebral lesion. Hemiplegias and monoplegias designate here, as elsewhere, paralysis of one side of the body and of one extremity respectively. We will consider later (*see* p. 655 *et seq.*) the spastic hemiplegias and monoplegias, and the acquired forms of spastic paraplegia and diplegia, and here concern ourselves only with the congenital spastic paraplegias and diplegias.

The syndrome was first described by W. J. Little in 1843 in his lectures on Deformities of the Human Frame, as "universal rigidity of the muscular system or of the flexor muscles only, in newborn infants," and it has since been designated as Little's disease. While Little did not limit the affection to diplegias, the term *Little's disease* has been largely used to designate, as his son states, "those cases in which both lower limbs are affected, but not the upper, and which are generally of congenital origin." There has been of late, however, a tendency to include in the Little syndrome both paraplegias and diplegias (Déjerine, Bing, van Gehuchten, Erb and others), that is, bilateral congenital spasticity of spinal as well as of cerebral origin. Until recently there has been no anatomical basis for a pure spinal type, and Oppenheim is still inclined to agree with Ziehen, who describes Little's disease under cerebral aplasias and dysplasias. However, in three cases of typical Little's disease, or rather syndrome, in which autopsy was performed, Déjerine found in two instances a primary medullary, but no cerebral, lesion. I can express no opinion on this statement, as there has been no opportunity for autopsy in the cases which have come under my observation. Nevertheless, I feel that Déjerine's classification is most logical, and, therefore, include in the Little syndrome "all congenital spastic rigidity which is more pronounced in the lower extremities and which is due to a lesion situated either in the upper Rolandic region or in the spinal cord, transverse myelitis." And in determining the most effective means of ameliorating the condition, we should take into consideration the fact that the causative lesion may be either cerebral or spinal, and attempt, whenever possible, to differentiate between the two types.

Etiology.—Little's syndrome, like many other congenital affections, cannot be attributed to any single etiological factor or pathological lesion. It is usual to find in these cases a history either of difficult labor or of premature birth. Allen's hypothesis in regard to the etiology of many of these cases is fully stated in the chapter on Physiology (*see* p. 120). He considers that a temporary arrest of circulation at the time of difficult labor may be largely responsible for changes in the crossed pyramidal tracts at that time not fully myelinated. These changes lay the foundation for a future sclerotic lesion. Little found, and our experience has borne out the statement, that these congenital paraplegias and diplegias were most frequently the result of accidents to the fetus during a prolonged and difficult labor. These birth traumatisms may be cerebral or

medullary and consist in corticomeningeal hemorrhage, hematomyelia or infection.

That many children with Little's disease are prematurely born is a fact which cannot be denied. One naturally draws the conclusion that there is agenesis or maldevelopment of the pyramidal tracts because of the early birth. However, inasmuch as Little's disease is not present in all prematurely born children, and since it does occur in children born at term, it seems more logical to suppose that both the premature birth and the spasticity are to be attributed to some common underlying factor. Among the possible causes of fetal infection or malformation, syphilis holds a place of prime importance (Déjerine, Oppenheim, Friedmann, *et al.*). That the number of syphilitic parents giving birth to children with the Little syndrome is not greater than the number of normal parents, Sachs explains on the ground of the frequency of abortions with the former. Delbet has proved the syphilitic diathesis in 13 cases of prematurely born children. Occasionally there seems to be no apparent cause for the syndrome; in such cases there may have been a prenatal cerebral or medullary lesion (Déjerine, Bing, *et al.*).

Pathological Anatomy.—Very numerous and varied are the pathologic processes found at autopsy. The lesions may be macroscopic or microscopic. They may consist in intra-uterine infections or lesions, such as porencephalus, myelitis or sclerosis, of agenesis or maldevelopment of the pyramidal tracts, or there may be an intracranial hemorrhage or hematomyelia.

As prenatal lesions Sachs mentions: (1) porencephalus, or depression of the upper surface of the brain caused by fetal encephalitis or meningitis; (2) lobar sclerosis or congenital encephalitis, which is a gliotic induration of the greater part of both hemispheres; (3) tuberous sclerosis, or small prominences in the cortex, especially the sensory motor region, which may reach the size of a nut and consist of hypertrophied glia; (4) cysts and processes of softening in the brain; (5) spinal foci of disease.

The natal lesions described by Sachs are: (1) defective development of the corticospinal tracts on account of premature birth; (2) hemorrhages into the brain substance or on the surface; (3) postpartum cerebral meningitis and encephalitis arising from infection through hematoma or contusion; (4) hematomyelia or hematorachis.

Actual agenesis does not play as important a part as one would suppose in the causation of the syndrome. In fact, it has been stated by Déjerine that no autopsy has thus far revealed a primary agenesis of the pyramidal tracts; in many cases, however, there is defective development of this portion of the nervous system secondary to some process, such as porencephalus or myelitis. In most of the postmortem examinations, lesions have been demonstrated involving the upper part of the Rolandic

region, due usually to intra-uterine infection. These lesions are often accompanied by a more or less acute hydrocephalus.

The controversy regarding the pure spinal origin of the Little syndrome has already been mentioned. The two cases reported by Déjerine, in which autopsy revealed a primary focus of infection of fetal origin in the upper cervical cord, a transverse myelitis, with secondary degeneration of the pyramidal tracts, are especially worthy of mention. Both cases are typical examples of the Little syndrome, and prove that a primary focus of infection in the spinal cord developing during fetal life may lead to secondary agenesis of the pyramidal tracts and result in genuine spastic paraplegia. There are cases on record in which a hypoplasia of the pyramidal tracts of the cord was found. Not infrequently the brain and cord will appear normal to the naked eye; indeed, cases have been reported in which no lesion was found. However, careful histological examination will usually reveal a lesion of the Rolandic cortex or the sensory motor tracts. The whole problem is a baffling one. In spite of the neurological data and anatomical and pathological facts at our disposal, we are still unable in the majority of instances to determine the exact nature or seat of the lesion.

Symptomatology.—While the clinical manifestations of Little's disease are fairly constant—with the exception of the cerebral symptoms which are present in some cases and lacking in others—nevertheless they vary greatly in degree, ranging from a slight hypertony of a single muscle or group of muscles to general rigidity of all four extremities and sometimes even of the muscles of the trunk and neck. Therefore, in selecting the proper method of treatment we must take into consideration, not only the type of spasticity, but also the severity of the symptoms and plan our operation accordingly. Needless to say, the same principle holds good in all cases, but the most radical measures should be reserved for those cases in which a large group of muscles are severely affected. Thus the choice between the Förster and the Stoffel operation, as well as the decision as to the number of roots to be resected, depends entirely upon our interpretation of the symptom-complex.

Even though congenital in origin, the anomalies of the Little syndrome are not always recognized immediately after birth; indeed, they sometimes pass unnoticed until the child begins to take his first steps. More often, however, the deformities are so pronounced that they obtrude themselves almost at once in the form of rigidity of the extremities, spasms of the adductors and internal rotators of the thighs, of the plantar flexors of the ankles and of the flexors of the knee. The picture becomes much clearer when the child first attempts to walk. All voluntary movements are executed slowly; the child learns to walk late, if at all, seldom being able to go alone before the age of four or five. The legs are rigid, the knees slightly flexed and the thighs so strongly in adduction that they

rub against each other in attempts to walk, while the feet are in typical talipes equinus. Thus, the patient walks on the tip of the toes with the so-called *scissor gait*. In many cases the rigidity and contractures are entirely confined to the lower extremities; in other cases the upper extremities are involved, although to a lesser degree, and sometimes even the facial muscles and those of the neck and trunk. In the severest cases the child can use neither his hands nor his feet. The upper arm is strongly adducted, the forearm flexed, the hand usually half flexed and pronated, the fingers flexed sometimes in all joints, sometimes only in the interphalangeal joints. There may be, especially during the early years, some weakness of the upper extremities. The reflexes are increased and even passive movements are extremely difficult; indeed, Oppenheim reports that in some cases he has found the shoulder blades so stiff that they could scarcely be pushed back against the thorax. Déjerine speaks of cases in which there was normal intellectual development when the face had a very vacant expression; or again the face may be normal in repose, but very much altered by spasmodic grimaces when the patient is addressed.

We find the tendon reflexes—particularly the patellar—markedly exaggerated, owing most likely to the permanent contracture of the gastrocnemius group. The Babinski sign is usually present, while ankle clonus is almost invariably lacking. Sensation is usually unimpaired, and disturbance of the bladder and rectum has been noted only in very rare, atypical cases. Other congenital anomalies and deformities, such as subluxation of the hip, kyphosis or scoliosis, may also be present.

Purely cerebral symptoms manifest themselves in the form of psychic disturbances, imbecility of high grade or complete idiocy, epilepsy of slight or severe degree, disturbances of speech due to the rigidity of the muscles of articulation, and the choreo-athetoid movements.

Thus the cases of the Little syndrome fall into two categories: in the one the spasmodic rigidity of the extremities is accompanied by cerebral symptoms; in the other the manifestations of cerebral disturbances are entirely lacking. Déjerine designates these as the cerebrospinal and the pure spinal types.

Granting that the Little syndrome may have a pure spinal, as well as a cerebral origin, it is extremely important that we should be able to distinguish between these two types. In some cases, particularly when the contractures are very slight and few concomitant symptoms are present, a differential diagnosis is practically impossible. But in cases with pronounced spasticity of the extremities, we should be able to determine fairly accurately at least the approximate seat of the lesion, that is, whether it is cerebral or spinal, even though we may not be able to judge its exact nature. What then are the distinguishing marks? This differential diagnosis, it seems to me, rests entirely upon the presence or the

absence of cerebral symptoms. In all cases in which there is a cerebral lesion extensive enough to cause marked spasticity of the lower extremities, we almost invariably find psychic disturbances varying from mild forms of epilepsy to complete idiocy, accompanied by a vacant expression of the face, athetoid movements, involvement of the ocular muscles, strabismus, disturbances of speech and sometimes paralysis of other cranial nerves and even pseudobulbar symptoms. On the other hand, if the cerebral symptoms are entirely lacking in a case of marked spastic paraplegia, it is safe to believe that the lesion is of spinal origin, and I am in entire accord with Déjerine's statement that the latter variety is not nearly so rare as heretofore supposed. In both Déjerine's cases in which a primary transverse myelitis was found at autopsy, the intelligence was unimpaired and facial expression was normal; yet the contractures were so severe in one case that the patient had never walked or used his hands. He lived to be sixty-six years of age. The autopsy showed the brain to be macroscopically and microscopically normal, but in the spinal cord, a focus of transverse sclerosis was found in the third cervical segment with degeneration of the columns of Goll and Burdach above the lesion, and sclerosis and agenesis of the crossed pyramidal tracts below the lesion.

Differential Diagnosis.—While the congenital origin, the course and certain of the clinical manifestations of the Little syndrome are sufficient in most instances to differentiate it from other forms of spasticity, nevertheless difficulties do arise, and it is occasionally confused with the acquired infantile spastic paraplegias and diplegias, spastic hemiplegia, the so-called hereditary spastic paraplegia and very rarely with spastic spinal paralysis (lateral sclerosis). Indeed this is not difficult to understand when one realizes that all spasticities of organic origin are due either to a break in the conductivity of the pyramidal tracts in the cord or to a lesion or defect of their centers in the brain, and that a variety of pathological lesions may be responsible for the break. Nevertheless, certain differences between the various types may be noted.

First, the acquired forms of spastic paraplegia and diplegia differ little in their clinical manifestations from the congenital variety. They do not appear, however, immediately after birth, and are usually the result of some infectious disease. Oppenheim has found that the acquired types frequently take the form of a bilateral hemiplegia and are associated with athetoid movements. Pure spastic hemiplegia is confined to one side of the body, and thus is easily differentiated. However, the more usual variety, the bilateral hemiplegia, presents a clinical picture very similar to that of the Little syndrome with the exception that the upper extremities are almost invariably involved to a marked degree, while in Little's disease the upper extremities are often quite normal, as in the following case which was under my care a few years ago:

Little's disease in a child of eleven. The upper extremities were normally developed, but the lower extremities were extremely spastic, the legs being constantly flexed at the knees and the feet in a position of equinovarus. Operation; laminectomy and section of the second, third, fourth and fifth lumbar and second sacral roots on the right side, followed by tendon transplantations. The spasticity was decreased and locomotion improved.

The patient, a boy, *aet.* 11, was admitted to my service at the University Hospital, Jan. 3, 1912 (File No. 23734). The child was unable to give any history except that his present condition had existed for as long as he could remember. His mentality was subnormal. His arms were well developed and his hands unusually large. The muscles of the lower extremities above the knees were well developed and spastic. The legs were constantly flexed at the knee and the feet in a position of slight equinovarus (Fig. 269). The knees could be forcibly extended without causing pain, and the patient could voluntarily flex and partially extend the knees. He was unable, however, to move the feet except in slight inversion.

Laminectomy, Jan. 16, 1912. A curved incision was made from the lower thoracic to the lower lumbar region with its convexity to the right. After separating the erector spinae muscles from either side and controlling hemorrhage with hot sponges, the spinous processes and laminae were removed to expose the third, fourth and fifth lumbar and first sacral roots. These were divided only on the left side, the operation concluded and the wound closed.

After this operation it was noticed that the ankle clonus on the left side was abolished, and the left leg could be abducted to an angle of 60 degrees without tilting the pelvis, on the right only to an angle of 30 degrees. On the left side there was no resistance to passive movements in the knee joint, while the condition on the right side was unchanged. In examining the patient in the face down position, hyperextension of the thigh was possible on the left side, but not on the right.

Jan. 30, 1912, at a second operation, following the line of the original incision, the muscles were separated and the dura exposed. In order to reach the second lumbar root, it was found necessary to remove the laminae and spinous processes of the second lumbar vertebra, and after opening the dura the second, third, fourth and fifth lumbar and second sacral roots were divided on the right side. A pledget of cotton saturated with 4 per cent stovain was applied to the cord and roots before their division. After complete hemostasis was established, the wound was closed with tier sutures. A note was made at the conclusion of this operation that because of the adherence of the overlying muscles to the surface of the dura and some adhesions within, the second stage of this operation was more difficult than the first. This might be advanced as an argument in favor of the one stage procedure.

The final operation was performed upon this patient, January 20, 1913. It consisted in tendon transplantations; on the right side the tendon of the sartorius was transplanted to the tendon of the quadriceps, and on the left side the tendon of the sartorius and the semitendinosus were transplanted into the tendon of the quadriceps femoris. Both legs were put in a plaster-of-Paris dressing.

As a result of the several procedures the degree of spasticity was diminished, the range of voluntary motion increased (Fig. 270), and to that extent locomotion was improved.

While hereditary and familial spastic spinal paralysis does not appear in most instances until adult life, it has been known to occur in children and adolescents; hence it should be differentiated from the true Little syndrome, as the latter occasionally occurs in several children in the same family. This is rarely a difficult matter, the congenital origin of the

FIG. 269.—A CASE OF SPASTIC PARAPLEGIA BEFORE OPERATION.
Showing the legs flexed at the knee.

FIG. 270.—PHOTOGRAPH OF PATIENT AFTER RESECTION OF THE POSTERIOR ROOTS.
Showing ability to flex the thighs sufficiently to elevate the foot from the floor.

Little syndrome and the later appearance and slower development of the hereditary type being the principal differential points.

Course and Prognosis.—The course and prognosis of this congenital anomaly vary according to the degree of the spasticity and muscular weakness, according to whether only the lower or all four extremities are affected, and finally and most important of all, according to whether the spastic rigidity is accompanied by cerebral disturbances. Due consideration should be given to these points before surgical intervention is undertaken. While the syndrome almost never completely disappears, it is not unusual in those cases where there are no cerebral disturbances and no muscular weakness to see the symptoms gradually retrogress with the development of the child. A certain degree of stiffness always remains in the lower extremities, but the upper extremities may become perfectly normal. In these cases there is no muscular atrophy and the symptoms may all be attributed to the spastic rigidity. On the other hand, where pronounced spasticity of the lower extremities combined with muscular weakness and marked cerebral symptoms obtains, the condition almost never improves even though the patient live to be middle-aged. It is evident, therefore, that the prognosis is most promising in the cases of spinal origin in which there are no cerebral symptoms and in which the spasticity is limited to the lower extremities, and most grave in the cerebrospinal cases, the gravity depending upon the degree of the accompanying muscular weakness, the extent of the intellectual impairment and the severitv of the associated athetoid movements.

Acquired Infantile Spastic Conditions

Inasmuch as cerebral disturbances and muscular atrophy are much more frequent in cases of acquired infantile spastic paralysis, section of the posterior nerve-roots is seldom so effective as in the congenital types. Rhizotomy, however, has been resorted to in 35 cases of acquired infantile spasticity, with marked improvement in 25 cases, no change in only 6 cases and 4 deaths (Table II, p. 676). I therefore feel that it should be given consideration in all cases in which the mentality of the patient is not seriously impaired or the muscular atrophy pronounced. The greatest care must be exercised in selecting the cases in this group; little is to be gained if the muscular atrophy render the limbs helpless after the spasticity has been overcome, or if the patient be not sufficiently intelligent to coöperate in the reëducation of the affected muscles after rhizotomy. It also should be borne in mind that children of low mentality are not good operative risks.

In the acquired types, as in the congenital varieties, we are dealing with a clinical conception or syndrome rather than with a definite disease. Indeed, here, as in the previous group, the etiology is still so obscure,

the fundamental anatomical lesions so varied, that it is quite impossible to determine either the exact nature or location of the causative morbid process of which the spasticity is but an end result. Infectious diseases, such as pneumonia, typhoid, measles, scarlet fever and trypanosomiasis, play an important part in the causation of infantile spastic paralysis, and the influence of syphilis is probably quite as great as in the prenatal types. Convulsions, eclampsia and trauma may be contributing factors.

The inflammatory processes, which develop during childhood and result in the infantile spastic paralyses, do not differ greatly from the prenatal or natal lesions of the congenital types, except that they are almost invariably confined to the brain, involving only one hemisphere and usually the lower rather than the upper portion of the Rolandic region. Encephalitis, hydrocephalus, chronic meningitis, sclerosis and cysts are among the most common of the postnatal lesions. While porencephalus is usually a congenital condition, Sachs mentions a pseudoporencephalus among the pathological processes of the acquired forms.

The symptom-complex of the infantile spastic paralysis simulates very closely that of the Little syndrome. There are certain differences, however, owing to the fact that in the former, the process is more circumscribed, involving in most instances only one hemisphere, and frequently only the lower portion of the motor area on that side. We have, therefore, a spastic hemiplegia instead of the congenital diplegia. The arms, particularly the hands, are involved more seriously than the legs, and the paralysis and muscular atrophy are more marked than in the Little syndrome. Synchronous with the spasticity we often find choreic twitching and associated athetoid movements, and occasionally a certain degree of ataxia. Cerebral disturbances are marked in the majority of cases, but by no means constant as in the following case.

Marked spasticity of the lower extremities and the left upper extremity in a boy of fourteen, whose mental development was entirely normal.

The patient, a boy, *aet.* 14, was admitted to my service at the University Hospital, January 23, 1912 (File No. 10983). The child was unable to give any account of his life except that he had once been able to walk, but that both legs and the left arm had been drawn up and useless for some time. He could not remember ever having been sick. His mental development was normal. The left arm was held slightly abducted, but it could be voluntarily adducted at the shoulder. This arm was flexed to an acute angle at the elbow and could be voluntarily straightened only to a right angle. The hand was flexed at right angles to the forearm and could not be moved. Slight movement was possible in the first three fingers, but impossible in the thumb and little finger. In both lower extremities the thigh was flexed on the trunk at right angles, the knee was flexed on the thigh and the foot at right angles to the leg (Fig. 271). There was but a small range of voluntary motion at the hip joints and practically none in the knee joint or in ankles or toes. Passive movements of the knee joint were possible only to a slight degree and with great effort. There was no ankle clonus; the Babinski was negative on both sides and the knee jerks were absent.

Spastic Spinal Paralysis (Lateral Sclerosis)

In addition to the congenital and infantile forms of spastic paralysis, we have to deal also with the spastic spinal paralysis of adults, the so-called lateral sclerosis. While this type is not regressive in character like so many of the cases of the Little syndrome, nevertheless it runs an extremely chronic course, and therefore should be favorably influenced by section of certain carefully selected posterior roots. As a matter of fact, in a few cases the improvement has been decided.

Clinically, spastic spinal paralysis, as described by Erb in 1875 and later by Charcot, has a well-defined symptom-complex; there is, however,

Fig. 271.—Photograph of Patient with Spastic Paraplegia.
Showing the thighs flexed on the trunk and the legs on the thighs. Note also the contracture of the left upper extremity.

still some doubt among clinicians and neuropathologists as to whether it constitutes a distinct pathological entity. According to Erb and Charcot and certain other writers, the spastic paresis of the lower extremities is caused by a primary degeneration of the lateral pyramidal columns of the spinal cord. Many cases, however, have been reported, which clinically would fall in this category, but in which quite different lesions (syphilitic processes, multiple sclerosis and even cerebral lesions) were revealed at autopsy. Nevertheless, in view of the fact that a primary and isolated lateral sclerosis has been found to be the anatomical lesion in a number of recently recorded cases, it seems just to grant a definite place to spastic spinal paralysis in the pathology as well as in the semiology of the nervous system. The disease is prone to develop in adults between the ages of twenty and forty. While little is known as to its exact etiology, it has been attributed to syphilis and other infectious diseases,

to lathyrus poisoning and saturnism. It has also been known to develop following overexertion or after trauma. The clinical picture in most instances is quite clear and distinct. It begins very gradually with stiffness and rigidity of the lower extremities, accompanied by spastic contractions and increased reflexes. Vasomotor and trophic disturbances are lacking even in the later stages; sensation is unimpaired, and the bladder and rectum function normal.

Hereditary and Familial Spastic Spinal Paralysis

There is another type of spastic spinal paralysis, the distinguishing feature of which is its hereditary predisposition. In other respects, it differs little from lateral sclerosis; and on account of its very chronic course this form of spasticity should be just as favorably influenced by timely section of the posterior roots as the one just described. In either case the procedure can be only palliative.

The affection was first described by Strümpell in 1893, and since that time isolated cases have been reported by Erb, Newmark, Tooth, Kühn, Raymond and Rose, Lorain and others. As its name indicates, the disease appears in successive degenerations, and often in seven children of the same family. It is more prone to develop in males than in females, and usually manifests itself between the twentieth and thirtieth year, occasionally earlier. The pathological anatomy of this type of spasticity is as yet but partially elucidated. In addition to the degeneration of the lateral pyramidal tracts (lateral sclerosis), there has also been found in most of the cases examined at autopsy a slight degeneration of Goll's column, of Clarke's column and sometimes of the direct pyramidal (anterior cerebrospinal) tracts and the dorso-spino-cerebellar tracts (Strümpell, Newmark). Also occasionally, as in the familial case reported by Raymond and Rose in 1909, no pathological lesion is discovered. We, therefore, are not dealing with a pure lateral sclerosis, but rather, as Oppenheim puts it, with a combined system disease, sometimes with an affection with no demonstrable pathological process, although in the majority of instances the lateral sclerosis dominates the picture.

The typical symptom-complex presented by the hereditary and familial spastic paraplegias differs little from that of the Erb and Charcot type just described. It begins with a pure spastic paraplegia, but the upper extremities are involved more rarely and at a later period. Moreover, in the later stages of the hereditary type slight sensory disturbances, cranial nerve involvement, weakness of the bladder and bulbar symptoms are observed. Sometimes it is the ocular muscles which are affected, sometimes those of the tongue or lips. Here, as in the other types of spasticity of organic origin, there is no single etiologic factor or fundamental lesion, and the clinical picture is subject to numerous variations.

Multiple or Disseminated Sclerosis

In view of the fact that multiple or disseminated sclerosis often progresses rapidly, little is to be gained by a resection of the posterior roots. Out of 11 cases of multiple sclerosis collected by Förster, in which rhizotomy had been performed, there were 4 deaths, 4 improvements, and 3 cases without success, the sclerosis progressing rapidly after the operation. In two cases operated on by Tietze, one patient died from decubitus, the other from cystitis; in Gottstein's case death was due to an influenzal infection; and the patient operated on by Küttner suffered a severe exacerbation of the symptoms fourteen days after the operation and died a few months later.

Thus, while in a few instances a certain amount of benefit is derived from rhizotomy, in most cases it is of little use to intervene because the process progresses rapidly to a fatal issue. Disseminated sclerosis should, therefore, be considered in this connection only for the purpose of differentiating it from the other spinal affections, with spastic phenomena, which may be benefited by section of the posterior roots. This differentiation is seldom difficult, since in multiple sclerosis we almost invariably find, associated with the symptoms of pure spastic spinal paralysis, certain ocular disturbances, such as optic atrophy or pallor of the temporal side of the optic disk, nystagmus, paralysis of the extrinsic ocular muscles, and more rarely, optic neuritis. Scanning speech, bradylalia and intention tremor are among the early symptoms, and occasionally headache, apoplectiform attacks and loss of memory are observed, while cutaneous sensation is usually unimpaired, and disturbance of the sphincters is rare. The frequent combination of ataxia with the spastic paraplegia is also a distinctive feature, and one often notes a variation of motor symptoms from time to time, as if the axis cylinders passing through affected foci were later enabled to take up their functions. While at first multiple sclerosis may simulate other affections of the spinal cord, in a short time the clinical picture becomes quite distinct and little difficulty is experienced in most instances in establishing the diagnosis.

Myelitis

Spastic spinal paralysis is also present, in association with other symptoms, in the various forms of myelitis; and in those cases in which the process is extremely chronic or has become stationary, rhizotomy may be of no little use in allaying the spastic contractures. Chronic myelitis often simulates bilateral sclerosis for some time, but sooner or later, certain marked differences appear, such as sensory disturbances in the form of paresthesias and anesthesia, affections of the bladder, and trophic disturbances. It is also to be remembered that myelitis, even in its most

chronic form, develops more rapidly than the so-called spastic spinal paralysis or lateral sclerosis.

Syphilitic myelitis and the resulting syphilitic spastic spinal paralysis may run a very slow course, and here rhizotomy has been resorted to, but with doubtful expediency, as a means of controlling the spastic contractures which in some cases become extreme. The clinical picture of syphilitic myelitis, while resembling that of the other forms of myelitis, is somewhat more varied, since the meninges and roots are often involved as well as the cord. The disease may usually be recognized by signs of infection in other parts of the body, by a history of lues, or by the variability of the symptoms, the involvement of certain extrinsic ocular muscles and inequality of the pupils. Whenever there is a suspicion that the spasticity is specific in origin, a serological test should be resorted to at once. Root resection for spasticity is only a palliative procedure at best, and is of no value unless the source of infection or irritation can ultimately be controlled by treatment.

Tuberculous Spondylitis (Pott's Disease)

While spasticity of the extremities is not always one of the cardinal symptoms in tuberculous spondylitis, it frequently occurs at some period during the course of the disease, and the question has, therefore, arisen as to whether section of certain posterior roots might not be applied as a palliative procedure. In a case of cervical tuberculous spondylitis in a girl of eleven with very pronounced spastic paraplegia, Tietze divided the third and fifth lumbar and second sacral roots on the left side, and the third lumbar and first sacral on the right side, with very good results. Five months after the operation the child was able to flex and extend the lower extremities, to walk with the aid of crutches and go upstairs alone by holding the banister (Figs. 272-274). The process had been present for eight years, manifesting itself in a marked kyphosis of the lower cervical and upper thoracic vertebrae, equinovarus, weakness and later very painful contractures in the lower extremities which were so pronounced that voluntary movements of the legs were practically impossible. A year before the rhizotomy, a cervical laminectomy revealed a sharp prominence, formed by the cervical vertebrae, which it was impossible to remove, and this operation was without success. The involuntary spastic movements were so extreme, even at night, that the child was unable to sleep, and resection of the posterior roots was, therefore, undertaken. This is the only case I have been able to find in which rhizotomy has been performed for spasticity due to tuberculous spondylitis. The field for such operations in tuberculous subjects must be very limited. Certain it is that operative intervention should not be thought of until the tuberculous process has been quiescent for at least two years.

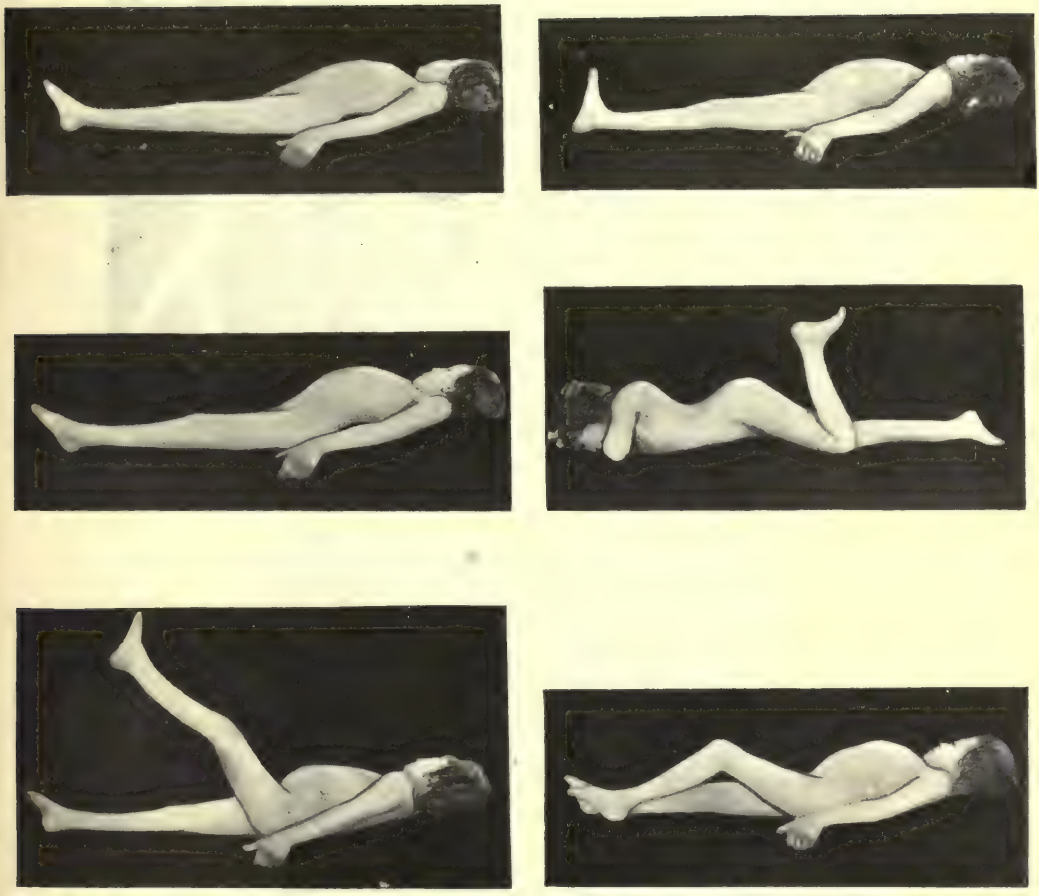


FIG. 272.—PATIENT FIVE MONTHS AFTER SECTION OF THE POSTERIOR ROOTS OF THE THIRD LUMBAR AND FIFTH SACRAL SEGMENTS ON THE LEFT SIDE, AND THE THIRD LUMBAR AND FIRST SACRAL ON THE RIGHT SIDE, FOR THE RELIEF OF SPASTICITY DUE TO POTT'S DISEASE. (From photographs in Tietze case.)

Showing ability to flex and extend both lower extremities.

FIG. 273.—SAME CASE AS IN FIG. 272, SHOWING THE PATIENT ABLE TO WALK WITH THE AID OF CRUTCHES FIVE MONTHS AFTER OPERATION. (Tietze case.)

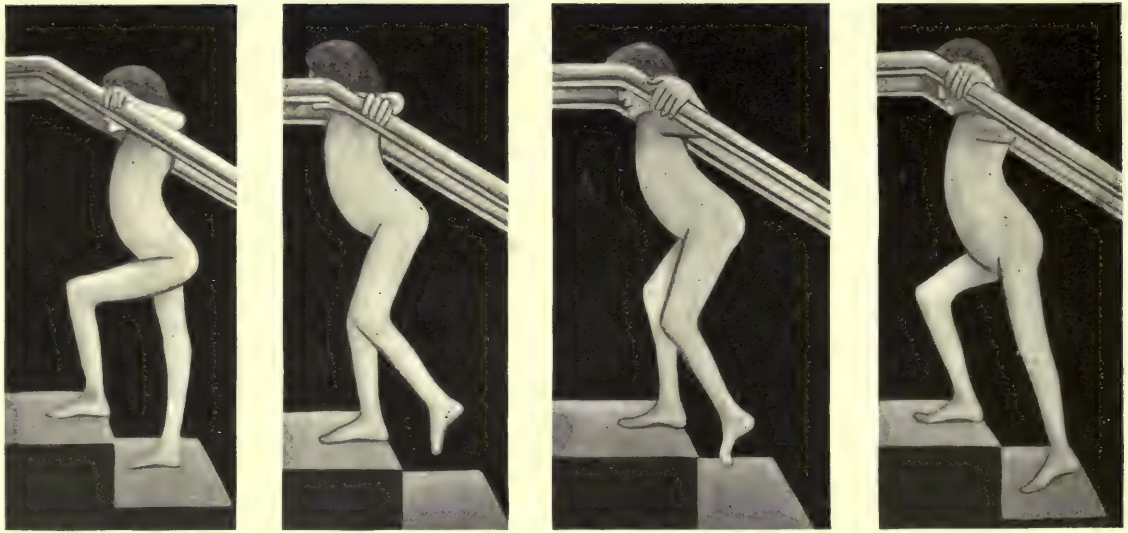


FIG. 274.—SAME CASE AS IN FIGS. 272 AND 273, SHOWING THE PATIENT ABLE TO GO UPSTAIRS ALONE BY HOLDING THE BANISTERS, FIVE MONTHS AFTER THE OPERATION. (Tietze case.)

Trauma

Spastic paralysis and rigidity of the extremities, so frequent after spinal trauma, is often one of the most distressing symptoms and may call for special treatment. The principle is the same here as in the other types of spasticity: the pyramidal tracts have been so compressed or destroyed by a fracture, dislocation or distortion of the vertebrae, by an intradural or extradural hemorrhage or by an hematomyelia, that the inhibitory fibers have been interrupted and spasticity of the lower extremities results in all cases where the lesion is situated above the lumbar enlargement. Stab wounds of the spinal cord have also been known to involve the pyramidal tracts to such a degree that they cause most distressing spastic contractures, as in the case recently reported by Wendel in which considerable benefit was derived from resection of certain posterior roots. Whenever there is persistent and severe spasticity and rigidity, following a spinal trauma, due consideration should be given to this method of lessening those stimuli which keep the muscles in almost constant motion when the inhibitory tracts from the brain have been interrupted.

Spinal Tumors

As we have already seen (*see* p. 529), spinal tumors, whether they arise in the vertebrae, in the meninges, or in the cord itself, may through irritation, compression or infiltration of the roots and pyramidal tracts, give rise to involuntary muscular spasms and spasmodic contractures. These spasms and contractures often persist even after the tumor has been removed, as in a case reported by von Eiselsberg, in which the removal of an intradural spindle-cell sarcoma from the level of the fifth thoracic segment had no effect on the very severe spasm and contractures of the lower extremities. In the hope of lessening these spastic phenomena, a rhizotomy was performed two months later, the second, third and fourth lumbar, and first sacral posterior roots being resected on both sides. There was no change in the condition for six months, at the end of which time improvement was noted; the patient began to walk with crutches, then with a cane, and finally—two and one-half years after the operation—the spasms almost entirely disappeared and the cane was abandoned. Removal of the tumor should always be considered first, and rhizotomy resorted to only as a palliative procedure when the radical operation is impracticable, or does not relieve the spasticity. Section of the posterior roots may be indicated for the relief of spasticity, as well as pain, in the inoperable, metastatic carcinomata of the vertebral column. Indeed, whenever we are confronted with the obstinate contractures of a spinal neoplasm, whatever its nature or origin, we should bear in mind the possibility of this means of relief.

Discussion of the Methods of Root Section

The treatment of spasticity by section of the posterior roots is a chapter in spinal surgery replete with interest. It was in 1908 that Förster recommended the interruption of the afferent impulses as a means of breaking the reflex arc and overcoming spasticity. The **physiological principles** upon which this operation is based have been discussed *in extenso* in the chapter on the Normal and Pathological Physiology of the Spinal Cord. It should be remembered that the subject of tonus and reflex activity depends upon the integrity of the reflex arc. No matter what the condition of relaxation, there is a constant reception by the sensory side of the cord of afferent impulses from muscles, joints and the integument, which impulses we consider sufficient to cause a certain tonic action of the anterior cornual cells. Let us take the case of the frog with spinal cord and the lumbosacral nerves intact. The lower limbs are held in a moderately tonic condition, the thigh drawn up slightly and the leg a trifle flexed on the thigh. Section of the nerves from the cord on one side will at once drop the corresponding limb into a position of complete flaccidity. Now this tonus, primarily dependent upon afferent impulses, is held in check by the reflex inhibitory mechanism from above. If this mechanism be destroyed, any afferent impulse which would normally travel through a reflex arc produces many times its normal result. Let us take as an example the groups of muscles on the anterior and posterior aspect of the thigh. Postulating a lesion in the neighborhood of the sixth and seventh thoracic segments, we find a condition of hypertonus of all reflex arcs below this level. The normal inhibition of the tonus of one group of muscles during the activity of its antagonistic group is either set aside or completely masked by the general hypertonicity of the part. Therefore, we are not able to demonstrate the reduction in tonic activity of the knee jerk at the time we have the posterior group of muscles in action. Such a patient in walking will cause a hypertonicity of the antagonist groups when he advances the lower limb, and it is very evident that the patient in such action is under the stress of increased work. He drags the leg forward with difficulty by the proper groups because it is being dragged backward at the same time by the antagonist groups. Again, in the passive movement of the lower limb, the very fact that one attempts to flex the thigh on the abdomen and the leg on the thigh sets in tonic activity those muscles which would normally tend to extend the leg and thigh, and one finds at once the locking of this joint system which in well-marked cases is so typical. Now the physiology becomes at once clear. Unfortunately, there is nothing we can do to restore the integrity of the reflex inhibitory mechanism. Therefore, our attention must be drawn to the other factor, namely, the reflex arc. There are two ways of solving the problem: the first, cutting the efferent root, the second, cutting the afferent root. The

former is, of course, absurd, as it would cause paralysis and grave trophic disorders. The second is the rational means, as it lessens or altogether obliterates the afferent impulses that cause the hypertonus. Hence the most ideal solution would be a section of posterior roots that would cut down the stream of afferent impulses to such a degree that the sum total of motor effect would be normal.

Indications and Contra-indications for Operation.—Section of the sensory roots is not to be regarded as a panacea for all forms of spasticity; the operation has its **indications and its contra-indications.** Physiologically stated, the operation is indicated only when the spasticity develops as a real reflex consequent upon the loss of cortico-inhibiting fibers. This would include, therefore, congenital spastic paraplegia (Little's disease), infantile spastic paraplegia, spasticity resulting from traumatic lesions or tumors of the cord, and with certain restrictions, the spasticity accompanying lateral and multiple sclerosis and Pott's disease. In most instances, however, multiple sclerosis should constitute a contra-indication, since the process progresses so rapidly that little is to be gained by a resection of the posterior roots. The scope of rhizotomy for Pott's disease is also very limited; the operation should never be resorted to until the tuberculous process has been quiescent for at least two years.

There are, however, many restrictions even in the eligible group, and of these the most important concerns the *degree of paralysis.* Were the paralysis such that, if relieved of the spasticity, the patient could not walk, obviously little would be gained by operation. A very slight degree of spasticity with marked paralysis is an unsuitable combination. It is a matter of the utmost necessity, therefore, that the degree of voluntary power be determined before a decision is made. Without the aid of measures which will during the examination control the spasticity, exact knowledge as to the strength of voluntary effort cannot be acquired. In complete spasticity of the legs there may be a considerable number of innervating pyramidal fibers intact, but the voluntary movement is absolutely inhibited by the uncontrollable muscle spasm. It is necessary, therefore, to resort to some method of temporary control, and this may be secured by temporarily interrupting the reflex arc through the anesthetization of the posterior roots as suggested by Goldscheider. In order to prove that the spasticity was the predominant feature in a case of spastic paraplegia following lues, Goldscheider injected stovain into the subdural space and in a very few minutes the patient was able to flex and extend both lower extremities and even to walk without support. The influence of the stovain passed off in a few hours and the spastic contractures returned. It has been stated by Clark and Taylor that placing the patient under ether narcosis, makes it possible to ascertain whether the spasticity is complicated by a high degree of paralysis of involuntary motion and trophic disturbances of the muscles. If the pyramidal fibers were entirely de-

stroyed, section of the roots would serve only to convert a spastic into a flaccid paralysis.

It is further essential that the subject be of *sound mind,* because the process of reëducation necessary after the operation, would be impossible were he so defective mentally as to make coöperation impossible. In the earlier stages of the development of this operation it was practiced in many instances upon children who, in addition to their spasticity of one variety or another, were mental defectives of various grades. The number of failures which followed, because of lack of coöperation, was so large that it proved convincingly that these subjects should not be included in the eligible class. I was fully convinced of this by the lack of improvement in one of my early cases in which the child was of very low grade mentality.

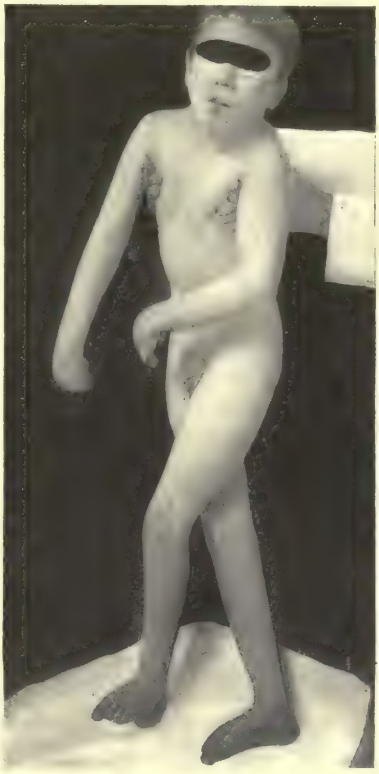


Fig. 275.—Photograph of Patient with Marked Spastic Paraplegia, Showing the Tendency of One Foot to Swing over in Front of the Other in Attempts at Locomotion.

Marked spastic paralysis and mental deficiency in a boy of eleven. No improvement following laminectomy and section of the posterior roots of the fifth, sixth, seventh and eighth cervical segments.

The patient, *aet.* 11, a little boy, was admitted to my service at the Episcopal Hospital, October 21, 1910 (File No. 1095). The child was healthy and normal up to one and a half years of age, at which time he could walk and talk a little. At this juncture, however, he had a fall on the stairs, and had since been unable to walk or talk. The spastic paralysis involved all four extremities, and the few movements he executed were incoördinate. His ankles were in a position of hyperflexion and were slightly everted. His wrists were flexed, and the first two joints of the fingers extended. If supported, he was able to force his feet forward, but each foot had a tendency to swing over in front of the other (Fig. 275). The only sounds he made were more like grunts.

Laminectomy, October 21, 1910. Under ether anesthesia, a curved incision was made in the lower cervical and upper thoracic region, and after the muscles were separated from the spine, the laminae and spinous processes of the fourth, fifth and sixth cervical vertebrae were removed, the dura opened and the posterior roots of the fifth, sixth, seventh and eighth cervical segments divided. The operation was unattended by any special difficulty, and the wound was closed with tier sutures.

Though the patient made an uneventful recovery from the operation, there was no functional improvement owing to the utter lack of coöperation on his part.

There are certain borderline cases, however, in which the exact degree of intelligence is doubtful, and in these it seems to me the patient should be given the benefit of the doubt. When the retardation in the development of the mental faculties is only slight, it frequently happens that improvement in the physical condition is followed by improvement in the mental condition. Therefore, while low grade imbeciles should be considered unsuitable subjects for rhizotomy, slight degrees of mental impairment, in the absence of other positive contra-indications, are not prohibitive.

Manifestly, the operation is one of such gravity that it *should not be practiced on the very young.* The consensus of opinion places the desirable age for operation between the fourth and seventh years; that is, at a time when the child has been automatically grounded in the principles of balance both in station and walking. The operation was performed once in a child two and a half years of age (Hildebrand), and Waugh advises the operation for children under three. The complex acts of station and progression require the development of certain automatic paths and centers which, under normal circumstances, would develop before the third year. Theoretically, therefore, the sooner the correction and training are begun, the better; practically, however, there have been no more striking results after operation before the third year than after operation between the fifth and seventh years, and the operative hazard is much less in the latter case. In my clinic the youngest patient was five years of age.

The propriety of operating for the relief of spasticity in *epileptic subjects* has been questioned, but to my way of thinking, no arbitrary lines should be drawn. The age of the patient, the stage of the disease, the frequency, severity and character of the attacks, must all be given consideration in the final analysis. Theoretically, one would suppose that the interruption of a portion of the afferent impulses to the cortex would have a decidedly beneficial effect upon epilepsy due to cortical instability, but this has not as yet been found to be true. That there is a greater risk in such cases one might assume from the experience of Küttner, two of whose patients died in epileptic seizures after the first stage of the operation.

A distinction must be made between spasticity without and spasticity with *athetoid movements.* Spiller in 1910 said that the association of athetosis must not be a deterring factor, as the strength of the limb is often increased by the excessive muscular action of athetosis. About that time in my service at the University Hospital there was a patient with violent and uncontrollable athetoid movements, chiefly of the upper extremities, and after consultation with Spiller, I decided to try the effect of root section. As will be seen from the case report, improvement was not marked, but this single clinical experience, because of the section of only a limited number of roots, must not be given too much weight.

No improvement following section of the posterior roots of the fifth, sixth, seventh and eighth cervical segments in a case of marked spasticity and athetosis of all four extremities.

The patient, a young man, *aet.* 24, was admitted to my service at the University Hospital a second time on January 5, 1910 (File No. 1105). For an account of the first operation in 1905, in which an attempt was made to overcome the athetosis by an operation upon the peripheral nerves, I refer the reader to page 692. At the time of his second admission, the condition of the lower extremities differed in no way from that noticed when he was under observation five years before. The motor disturbances of the upper extremities, which exhibited some transitory improvement following the elaborate cross anastomosis of the peripheral nerves of the brachial plexus, were quite as exaggerated now as they had been at any time. All the characteristic features of an infantile spastic diplegia were present, including the spasticity and muscular contractures, not of the stabile type, but those in which, accompanying voluntary movements, there was a spastic innervation of the muscles, so that every muscular effort caused spasms which interfered with any simple movement. Voluntary or associated movements were most pronounced and involved not only the upper extremities but the neck, back and lower extremities. The excessive spasticity, especially of the flexor and adductor groups, rendered any voluntary movements a matter of the greatest difficulty. The forearm was usually forcibly flexed on the arm and frequently the upper extremity viciously held in the grasp of the adductors behind the trunk, a position which the patient was powerless to change. The action of the spastic muscles could be overcome only by use of great force. The patient was absolutely a cripple; he could not feed himself, he was dressed and undressed only with the greatest difficulty, and the violent muscular movements wrought havoc on his clothes.

Laminectomy, January 8, 1910. *First Stage.* Section of the seventh and eighth posterior cervical roots. Under ether anesthesia, a curved incision was made from just above the fourth cervical to just below the first thoracic vertebra. Two guide sutures were introduced in the skin on either side opposite the intervertebral disks, one between the seventh cervical and first thoracic, and the other between the fifth and sixth cervical vertebrae. The roots were to be identified by their points of emergence from the dural sac as follows: the seventh cervical root leaves the dural sac between the sixth and seventh cervical vertebrae; the eighth cervical root leaves the dural sac between the seventh cervical and first thoracic vertebrae. By removing the laminae of the seventh cervical and only a portion of the sixth, the seventh and eighth roots were exposed and divided. So much time had already elapsed because of the free bleeding and the difficulty in gaining access to the canal at that level that it was decided to postpone until a future date section of the fifth and sixth roots as originally contemplated. In dividing the roots, it was not possible even with the aid of a powerful magnifying glass to recognize and isolate the arteries accompanying them.

A rather interesting observation was made in the diffusion of solutions used for spinal anesthesia. Just before the dural sac was opened in the cervical region, 1 c.c. of sterile water stained with indigocarmin was injected between the first and second lumbar vertebrae, the point of selection for injections in spinal anesthesia. The dural sac in the cervical region was immediately opened, but there was no sign of the colored fluid coming from the canal at any time during the operation, despite the fact that cerebrospinal fluid was flowing quite freely from the wound and the patient was in the horizontal position.

Second Stage. February 17, 1910. The second stage of the operation was not

performed until six weeks later. Realizing the difficulties experienced at the first operation, it was decided to adopt a different method of procedure. As the third and fourth cervical vertebrae are not far distant from the base of the skull, it was decided to adopt the same technic as for suboccipital craniectomy. Accordingly, with the patient on his side, table elevated and head flexed, a crossbow incision was made down to the aponeurosis, with the horizontal limb on a level with the tip of the mastoid process. The aponeurosis was divided in the median line, the muscles separated until the spinous processes of the second, third, and fourth cervical vertebrae were exposed; the two latter, and the right half of the laminae of the fourth and fifth cervical vertebrae were removed. The dura sac was opened and the fifth and sixth roots divided on either side. There was some discussion at the time as to whether the fifth and sixth or the sixth and an uncut portion of the seventh were removed, because what was taken for the fifth came off the cord at the level of the spinous process of the third cervical vertebra, which is a little low for the fifth and a little high for the sixth. As there was no doubt that two whole roots were divided at the first operation, the seventh and eighth, it was natural to assume that the two roots divided at the second operation were the fifth and sixth. An attempt was made again to isolate the artery from the root, but to no avail. The wounds were closed with tier sutures.

Following both operations the patient suffered not inconsiderably from root pains, and especially after the second operation there was free perspiration about the face, head and neck continuing for several weeks. Some improvement was noted after the first of the two operations, that is, there was less spasticity and some voluntary motion at either wrist. The last examination was made April 20, 1910, about two months after the second operation, with the following result:

Passive Movements. Right upper extremity: While the spasticity is less than it was before, there is still enough to make it difficult to extend the forearm on the arm; the wrist, however, is easily extended on the forearm; the fingers are in a state of extreme flexion, due probably to the shortening of the flexor tendons. Left upper extremity: Here the spasticity is not nearly so marked; the forearm can be brought to a right angle with ease and without much difficulty extended on the arm; the movements at the wrist in this as in the other arm are free and unimpeded; the fingers are in complete flexion owing to the shortening of the flexor tendons.

Voluntary Movements. Right upper extremity: The patient can put his hand to his mouth, to his forehead and to his ear without much difficulty; he can flex the forearm or arm and can flex and extend the hand on the forearm (dorsal and palmar flexion). Left upper extremity: The patient can put his hand to mouth, nose, forehead and ear; he cannot, however, extend the forearm beyond a right angle. The movements at the wrist joint are, if anything, freer and more easily accomplished than on the right side. Individual voluntary movements of any of the joints is practically impossible; any attempt at voluntary flexion or extension of an individual joint in either extremity is associated with movements of other joints, both homolateral and contralateral. Not only are the associated movements marked in both upper extremities, but almost equally so in the neck, back and lower extremities. The root pains, so severe immediately after the operation and persisting for almost seven weeks, have practically disappeared.

In comparing his condition now, some eight weeks after the operation, with that which existed prior to the operation, the patient regards his condition as improved in that he has more control over the movements of the arms. Whereas, before the operation the right arm was forced involuntarily behind the back, he is now able to keep it in front, and with both arms he can make voluntary movements which prior to the operation were impossible. The athetoid movements, so con-

spicuous before the operation, have practically disappeared, except in concentrated effort to make certain movements. In this respect there is a very striking change for the better. The after treatment has consisted in passive motion, in massage and in the practice of graduated exercises.

Since that time continued discussion of the subject and observation of the experience of others have clarified the situation and led me to look upon athetosis as a positive contra-indication for root resection. This conclusion is based upon the general principle that this operation can only be successful when the muscular spasm is due to lack of inhibitory control of sensory impulses to the gray matter of the spinal cord, as for example, in Little's disease, and not to an overcharge of motor impulses that originate in the centers of the brain, as is the case in athetosis and in epilepsy, spasmodic torticollis and diseases of that character. This distinction, therefore, between the character of impulses, as between those of sensory and those of motor source, may be made the basis for the elimination of this group of diseases of which athetosis is one, and in which involuntary and uncontrollable muscular excitability is the dominant feature. Including the case just described, resection of the roots for athetosis has been reported fourteen times, according to Förster, who states that the results have been mostly bad, and in a number of cases the athetosis has been increased.

In considering the indications and the contra-indications for rhizotomy mention should be made of the *extent and nature of the underlying lesion.* In a rapidly developing process where there is evidence of progressive involvement of the pyramidal tracts, the operation is contra-indicated because of the mutability of the lesion. In selecting cases for operation, therefore, only those should be chosen in which the process is either stationary or of slow development. When only a small group of muscles is involved or when the spasticity is not of sufficient severity to handicap the patient seriously, an operation of such gravity should not be considered.

Experience has taught us that for reasons not thoroughly understood the section of the roots has not been sufficiently helpful in relieving spasticity of the upper extremities to justify its performance. Even though there may be a transitory improvement, as was observed in one of my own cases, there is a greater tendency for recurrence in the arm than in the leg. Hence the operation finds its field of usefulness chiefly in the more severe grades of spasticity of the lower extremities.

Whether or not to operate when the process is known to be *syphilitic* is a debatable question. Certainly, resort should not be had to surgical interference until the possible effects of a thorough course of antisyphilitic treatment have been noted. Even in cases of failure to influence the spasticity by such measures, one hesitates because of the natural tendency of the process toward progressive involvement of the affected bundles or to the outbreak of the disease at other levels of the cord. Theoretically,

therefore, justifiable grounds for operation in syphilitic lesions will be found only in the exceptional case; as a matter of fact, in my clinic, I find that the operation has been resorted to but once.

Marked spasticity in a young man 32 years of age who had developed syphilis fifteen years before. Operation; laminectomy and section of the posterior roots of the fourth and fifth lumbar and first sacral segments. Death six days after operation. No autopsy and cause of death undetermined.

The patient, a young man, *aet.* 32, was admitted to my service at the University Hospital, September 14, 1913 (File No. 24347). His family history was negative. He used tobacco moderately, but no alcoholics. Fifteen years before he had developed syphilis, and specific treatment was instituted. He had had gonorrhea several times. Seven years prior to admission the patient first noticed that he became tired very quickly while walking. This weakness gradually increased, until upon admission he was unable to walk alone or even to stand without support. One year before, his left arm became weaker, and he was troubled with occasional loss of control of bowels and frequent micturition.

Physical Examination.—Sensory Disturbances. Pain sensation was unimpaired, but there was slight impairment of touch and deep sensations. The left hand felt as though a glove were on it. *Motor Disturbances.* The patient would lie in bed with the thighs strongly adducted, the left foot pronated, and all toes somewhat extended. After a few moments, however, he would be able to separate the legs a little. He could flex and extend the thigh on the abdomen on the right side after the spasticity was overcome. The knee could be readily extended in both legs, but flexion was difficult. Flexion and extension of the feet were unimpaired. In a sitting posture attempt to extend the leg on the thigh met with resistance almost immediately, which could not be overcome. By flexing the thigh, he could raise the foot off the floor on both sides. In this same position he could flex both big toes, but none of the smaller ones, nor could he flex the ankles sufficiently to raise the balls of the feet from the floor. In the erect posture, he could not flex the toes, but with great effort he was able to lift the foot about 6 cm. from the floor. Standing with the aid of one cane, he could flex neither the toes nor the ankle, and he was able to raise the foot from the floor only for a fraction of a second.

Laminectomy, September 20, 1913. A curved incision was made so as to expose the fourth and fifth lumbar and first sacral vertebrae; the aponeurosis was divided, and the spinous processes and the laminae of the fourth and fifth lumbar removed. During the course of the operation, a pledget of cotton saturated with a stovain solution was kept almost continuously on the cord after the dura was opened at the upper angle of the wound. The root passing out in the interspace between the first and second lumbar vertebrae was identified as L_4. Stimulation of the anterior root of this segment, however, produced marked flexion instead of extension, and from this it was assumed that L_3 instead of L_4 supplied the extensor reflex of the knee. Therefore, L_4 was cut on both sides, and afterwards, L_5 and S_1. The second sacral root was identified as the last to leave the sac within the exposure. It was extremely small and there appeared to be no way of separating the posterior from the anterior root, so that we had to abandon our original intention of including S_2 with the number of roots to be cut. The wound was closed with tier sutures. After this the patient complained more or less constantly of pain up to the time of his death on the sixth day. No autopsy was permitted, and the

cause of death was undetermined. The wound had healed by first intention, so that the possibility of infection as a cause was eliminated.

The *physical condition* of the patient should be such as to warrant a major surgical undertaking. When there is extreme emaciation, when the muscles have undergone atrophy to an extreme degree from disease and prolonged confinement to bed, and especially when decubitus has already developed, the subject should not be operated upon. He should be reasonably well nourished and with more than a vestige of musculature upon which to build and to train.

Selection of Roots.—Without doubt the most important technical consideration is the selection of the roots to be cut. The supply of each muscle or group of muscles is represented in most instances by three segments of the cord and by as many roots, and the cutaneous nerve supply of any given area is derived from at least three roots. Theoretically, it is designed to break the reflex arc of the involved muscles by cutting off as many peripheral stimuli as possible; not, of course, to remove every source of sensory stimulation, for in so doing a condition of flaccidity and absolute anesthesia would be substituted for the spasticity. As a general working principle, I plan to cut two out of every three possible sources of sensory stimulation, or, to put it in a different way, two of the three roots from which a given group of muscles derives its sensory supply.

As the operation is practiced chiefly for the relief of spasticity in the lower extremities, the lumbosacral plexus will be considered first. The following table gives the sensory distribution to the muscles:

Flexors of the thigh: L_1, L_2, L_3, L_4, L_5, S_1
Extensors of the thigh: L_2, S_1, S_2
Adductors of the thigh: L_2, L_3, L_4, (L_5)
Abductors of the thigh: L_5, S_1, S_2
External rotators of the thigh: L_5, S_1, S_2
Internal rotators of the thigh: L_3, L_4, L_5, S_1, S_2
Extensors of the leg: L_2, L_3, L_4
Flexors of the leg: L_5, S_1, S_2
Dorsal flexors of the foot: L_4, L_5, S_1
Plantar flexors of the foot: L_5, S_1, S_2

Thus in the selection of roots there are seven to be considered, the five lumbar and the first two sacral, and in applying the rule not to cut more than two successive roots we take into consideration, first, whether the case is of moderate or severe grade, and, secondly, what groups of muscles are most involved. In the majority of instances, the muscles most seriously affected are the adductors of the thigh, the hamstrings and the calf muscles, but one group may be very much more at fault

than another. For discussion, let us say that in many cases the following groups will meet all the indications, L_2, L_3, L_5, S_1, S_2. Under what circumstances should there be any departure from this selection? In the first place, Förster advises the substitution of L_4 for L_3 when L_3 instead of L_4 is the source of the extensor reflex of the knee, and states that this may be determined on the operating table by faradic stimulation. As a rule, however, the extensor reflex of the knee, so necessary for standing or walking, is maintained if L_4 be left intact. In aggravated forms when spasticity of the extensor group seems to predominate, the best selection, as Förster has pointed out, is L_1, L_2, L_4, S_1, and S_2, and when spasticity of the flexor group predominates L_1, L_2, L_3, L_5, S_1, and S_2. If it be true that the hypogastric mechanism of the bladder and rectum is largely dependent upon the first and second lumbar segments, it is questionable whether both posterior roots should be sacrificed. Moreover, there seems little reason for cutting the first lumbar, if the second and third be cut. Only under very exceptional circumstances, as in the case just mentioned, will six roots have to be sacrificed. The average maximum number is five roots, but there are occasions, as in the milder forms, when the cutting of three roots has sufficed. Following an injury to the cord with great reflex excitability of the flexor group, with aggravated spasticity in the hip and but slight contractures of the foot and knee, Wendel succeeded in relieving the condition by sacrificing only L_3, L_5 and S_2. That other operators have secured similarly satisfactory results by limiting the section to three properly selected roots is ample evidence of the propriety of limiting the resection to three roots in appropriate circumstances. But this should by no means deter us from including one, two, or even three more roots when the distribution of the spasticity demands it.

I am not in sympathy with the opposition of Codivilla to dividing more than three roots. He maintains that if too many roots be divided, there is danger of the limb becoming helpless because nutritional disturbance of the ganglionic cells in the anterior horn will lead to muscular atrophy. We must admit that after section of many roots, as in cases of tabes, the tone of the muscles is impaired, but the condition is one of ataxia rather than paralysis. As an alternative to resecting two of any three successive roots, Clark and Taylor resected a portion of all the roots. For example, in one instance, they divided one-half of each root from L_1 to S_2 on both sides. This modification, they claim, is just as effective as the more usual procedure, but since I have had no experience with it and know of no other surgeon who has had, I would make no further comment.

As stated in the chapter on The Normal and Pathological Physiology of the Spinal Cord and also under the contra-indications mentioned above, we must ever bear in mind the inevitable progress of most of the upper

motor neuron lesions. The patient may at the time of examination present a spasticity commensurate to a moderate lesion of the lateral tracts, so moderate, indeed, that section of three posterior roots may suffice to bring down the tonic effect to apparently normal. But we must consider the possibility of being called upon in a year or two to cut two or three more posterior roots owing to an extension of the causative lesion. In other words, the operation, though safe, is sufficiently serious to cause us to look ahead, and if possible, obviate the necessity of a second operation.

Turning now to the spasticities of the upper extremities, I have come to the conclusion that the best results are to be obtained by dividing C_4, C_5, C_7, C_8, T_1 and T_2. Förster suggests as an alternative that the larger portion of the fasciculi of each root from C_4 to T_2, including C_6, may be divided. Occasionally, the spasticity may be alleviated by section of a fewer number of roots, as in one of Clark and Taylor's cases of right-sided brachial spasticity in which the rhizotomy was confined to C_4, C_5, C_6 and C_7, and the spasticity considerably improved. As a rule, however, when the entire upper extremity is involved in the spastic contractures, the more extensive section is necessary, since the muscles of the upper extremities receive their nerve supply from C_4 to T_2.

Results.— To give a comprehensive picture of what has been accomplished by posterior root section, I have collected the reports of all cases published up to June, 1915. All told, they number 135 and are representative both as to the variety of lesions and geographical distribution of the surgeons (Table II). No doubt a few reports have been overlooked and probably a very much larger number of operations have been performed that have not been recorded. At the same time, the number of published observations is large enough for the purpose of analysis and representative enough to justify the drawing of conclusions as to the results, both immediate and ultimate.

Out of 135 operations there were 16 operative deaths, a mortality of 12 per cent. To be sure there are series from individual clinics in which the mortality in some may be larger, in others smaller. The mortality returned from the clinic of Küttner, who operated upon 33 cases with 3 deaths, is 9.1 per cent. Two of the three patients died in an epileptic seizure. The first twelve operations by von Eiselsberg were without fatalities, but the thirteenth patient died (7.7 per cent). Out of fourteen occasions in which I have been called upon to divide the posterior roots there were two deaths: one of a child five years of age who died suddenly on the day following the operation, the other of a man in his thirty-second year with syphilitic myelitis, who died a week after the operation from causes undetermined. The wound had healed by first intention and there was no evidence of any complication attributable to the operation.

TABLE II

RESULTS OF RESECTION OF THE POSTERIOR ROOTS IN 135 CASES OF SPASTICITY

	Practically Cured	Greatly Improved	Improved	Unimproved	Operative Death	Later Death		Total
						Improved until Death	Unimproved until Death	
Little's syndrome	2	33	23	3	9	..	..	70
Infantile spastic paralysis	..	12	13	6	3	1	..	35
Spastic spinal paralysis (Lateral sclerosis)	..	2	3	..	2	1	1	9
Multiple sclerosis	..	1	3	1	2	..	2	9
Spasmodic torticollis	2	..	..	..	..	..	..	2
Spasticity of traumatic origin	..	..	2	1	..	..	..	3
Spasticity due to pressure of tumors	..	..	1	..	..	1	..	2
Pott's disease	..	1	1	..	..	..	..	2
Hemiplegia	..	1	1	..	..	..	1	3
TOTAL	4	50	47	11	16	3	4	135

Many factors may influence the mortality; the age of the patient, the nature of the lesion, the mental and physical state, the presence of decubitus, the extent and number of roots divided—all of these must be taken into account. By the elimination of the unfit one may be able to keep the mortality down to at least the minimum recorded death rate, 7.5 per cent. Let the reader bear in mind that the child, or the young adult, who for years has been incapacitated, deprived of the advantages of open air exercise and handicapped by confinement to bed or close quarters, is very far from the physical state best fitted to withstand the effects of a major operation dealing with the cerebrospinal system. The propriety of operating is not under discussion here, but granting its justifiability, the mortality rate as recorded is by no means discreditable, but rather a tribute to the accomplishments of neurological surgery under adverse conditions. Whatever the indications for opening the dural sac, the most frequent cause of death in those who succumb to the operation is meningitis, although this should be avoided. So after posterior root section the most frequent causes of death in the sixteen fatal cases were meningitis and shock (Table III). Unquestionably in this operation these are the Scylla and Charybdis upon which life is most frequently wrecked. Yet both of these ought to come within the avoidable disasters in large measure, the first more so than the second. Shock prevention in this field involves the elimination of the unfit, the question of a one or two-stage operation, the avoidance of trauma, the application of the stovain block and other

TABLE III

CAUSES OF DEATH FOLLOWING SECTION OF THE POSTERIOR ROOTS FOR SPASTICITY

	No. Cases	Time Since Operation
Loss cerebrospinal fluid	1	same day
Shock	1	same day
Meningitis	5	5; 6; 13; 20; 20 days
Cardiac paralysis	1	same day
Tuberculosis (general)	1	7th day
No cause stated	4	2; 2; 3; 5 days
Acute enteritis	1	3rd day
Pneumonia	1	shortly after operation
Influenza sepsis	1	shortly after operation
	16	

features to be considered in detail under the technic of the operation. Of the causes of death after the first month, mention may be made of erysipelas, cerebral disturbance, inanition, tuberculosis and pyelonephritis.

In a critical analysis of the results of this operation one should bear in mind that recovery or cure, in the ordinary sense of the term, which implies complete restoration of function, is virtually impossible; first, because the spasticity is usually not entirely abolished, and secondly, because there still remains the muscular palsy. For these reasons the most that one can hope for is improvement, and the result must be judged according to whether the improvement is striking, whether the patient has been set free from the grip of his spasticity, whether from a bedridden condition he is able to get about in any fashion, or whether, from a condition of crippled and halted gait, he is able to move about with greater ease and facility.

There is no doubt in my mind that the operation is founded upon sound physiological principles. As a standard by which success or failure in practice may be measured, Waugh believes a case should be selected in which other measures have failed. The true value of the operation can only be appraised, according to Waugh, if its application be restricted to those cases in which the patient has already derived the maximum amount of benefit from other methods of treatment, massage, tendon lengthening and educational movements, and in which the residual disability is permanently relieved by section of posterior nerve roots. This standard is not applicable to a great many cases. No one questions the propriety of utilizing the simpler methods, such as massage, orthopedic appliances, and operations upon the tendons and muscles. However, in the case of aggravated spasticity, none of these measures, either individually or collectively, can relieve the spasticity even though the position

of the limb be improved. There will be but little, if any, return of control of voluntary movement, for the simple reason that the spasticity still remains and nothing has been done to overcome it. Therefore, I feel we must qualify Waugh's criterion as to failure or success in this operation, and consider that the result must be measured in terms of greater or less spasticity. Having adopted a standard by which to measure the results, partial or complete failure must not be charged against the principle of the operation, but to other factors, chief among which are the selection of unsuitable cases and the section of either of an insufficient number or an improper grouping of the roots. With these prefatory remarks, we take up the result as obtained in the individual diseases.

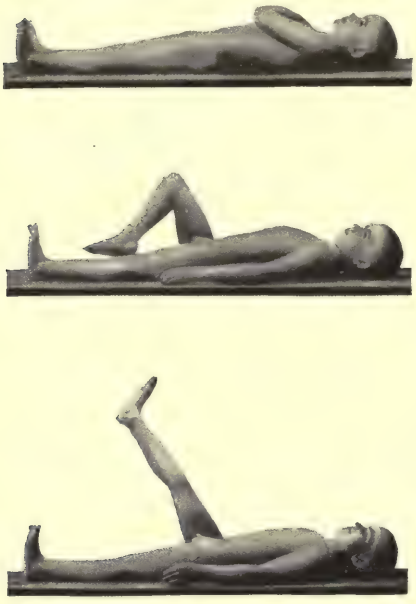


FIG. 276.—A KÜTTNER CASE AFTER RESECTION OF THE POSTERIOR ROOTS.

The patient is able to lie with the limbs extended, to place the heel upon the knee without associated flexion of the foot and to elevate the right lower extremity without associated flexion of the left leg or arm, the right knee or foot.

Little's disease occupies the leading position in this discussion, because it presents the conditions most likely to be influenced by this operation and far outnumbers any other lesion. In our collection of 135 cases, 70 were cases of Little's disease, 35 of infantile spastic paraplegia, and 9 each of multiple sclerosis and lateral sclerosis. As recorded in the authors' narratives, of the total 70 cases 2 were cured, 33 greatly improved, 23 improved, 3 unimproved, and there were 9 deaths. To indulge in a discussion of these several groups in general terms would lead us nowhere, but a concrete example of what has been accomplished by the operation in an individual case would be most instructive. Here, for example, is the record of a child operated upon by Küttner:

The patient, a boy, *aet.* 8, was born of healthy parents and had two normal brothers and sisters. When the child began to walk at the age of one year it was noted that its legs were stiff and knocked together. He was very slow in learning to talk; in fact, he could scarcely be understood and was generally backward in his mental development.

His musculature was flaccid; the arms showed a slight ataxia, and there was a marked hypotony of the flexors of the fingers. When on his back both legs were strongly flexed, adducted and rotated inward, flexed at the knee and at the ankle in a middle position between plantar flexion and dorsal flexion. In both lower ex-

tremities there were slight involuntary choreiform twitchings. On attempting passive movements in the legs there was marked spastic resistance of all muscles at the hip. Flexion, adduction and inward rotation were impossible. The resistance of the extensors to passive flexion at the hip joint was so great that the abdomen and the other leg were raised from the bed. Passive flexion of the knee was impossible.

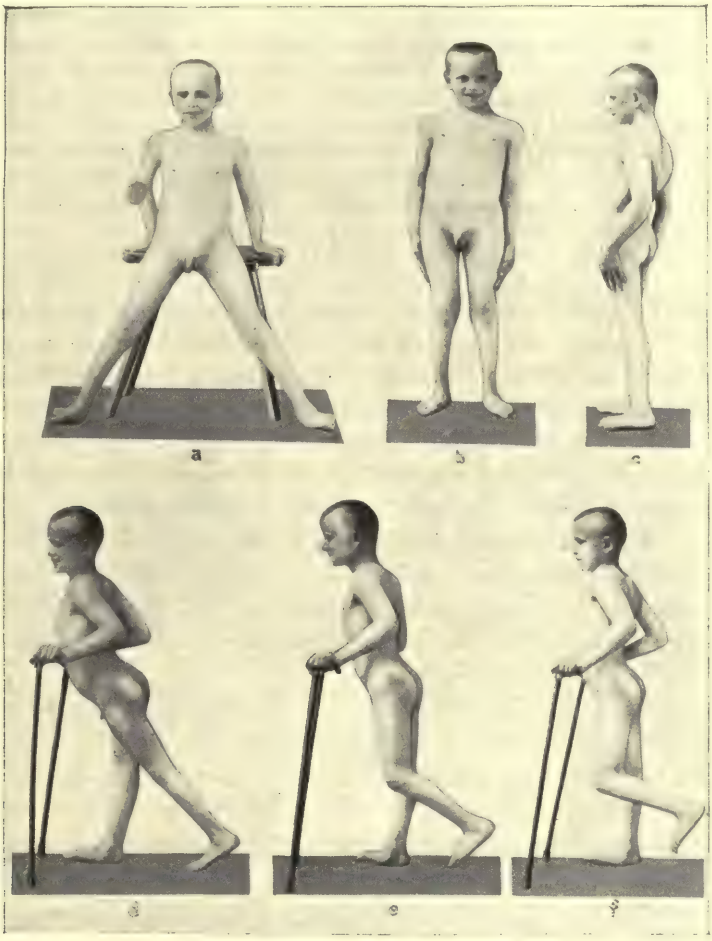


FIG. 277.—A KÜTTNER CASE AFTER RESECTION OF THE POSTERIOR ROOTS.

a, The patient is able to stand with limbs widely adducted; *b*, to stand alone in natural position; *c*, to stand with the lower extremities and back extended; *d*, to raise the heel from the floor with the right knee extended; *e* and *f*, to flex the leg on the thigh.

The foot was very stiff and could be moved passively neither dorsalward nor plantarward. Voluntary movements were also very much restricted. The leg could be flexed at the hip and the knee only with great difficulty and only with associated flexion of the foot and of the other leg, as well as further flexion of the vertebral column and the head, sometimes even with flexion of the arms as well. The reflexes were very much exaggerated, but sensibility was normal. A laminectomy was per-

formed by Küttner, July 8, 1908. At the first operation the laminae of the first to the fifth lumbar vertebrae were removed. At the second operation three days later an incision was made in the dura and the posterior roots of the second, third and fifth lumbar and second sacral roots were resected.

The child made an excellent operative recovery and began at once to gain both mentally and physically. A careful course of postoperative treatment with exercises and massage was pursued. To overcome the tendency toward inward rotation, which still persisted, the tensor fasciae latae and the gracilis were resected on both sides and later the tendon of the tibialis posticus was shortened. Two years after the resection of the roots the boy was able to lie flat on his back and to flex and extend one leg without associated movements in the other leg or in other parts of the body (Fig. 276). He was able to stand alone with his leg in normal position (Fig. 277), and could walk firmly and quickly with the aid of two canes, and a little with no support whatever. His mental condition was much improved also.

Under *infantile spastic paralysis* are included chiefly the palsies which follow infectious diseases, such as cerebrospinal meningitis, and those which differ from Little's disease chiefly in that cerebral disturbances and athetosis are more frequent, muscular atrophy more pronounced and the upper extremities more often affected. Because of the mental disturbances, athetosis and upper extremity involvement, the prognosis necessarily is not so good as in Little's disease. Again referring to Table II, there are 12 out of 35 cases said to be greatly improved, 13 improved, 6 unimproved, 3 immediate deaths and 1 later death. The mentally defective child is not a promising subject and athetosis is entirely uninfluenced by the operation, but where there are no such encumbrances much may be accomplished by root section.

A distinction has been made in our classification between the infantile spastic paralysis of the foregoing paragraph and the *spastic spinal paralysis* of adult age, when the lesion is essentially a lateral sclerosis and the origin usually syphilis. Good, bad or indifferent results here will depend in great measure upon whether the process is stationary. Where there have been complete failures, the disease had not been arrested because of progressive involvement of the cord.

The toll is too high to permit the inclusion of *multiple sclerosis* among the operable lesions. That the disease is not stationary but progressive, that the patient is, as a rule, in consequence of the disease, a poor operative risk should be accepted as contra-indications. In one of Küttner's cases there was complete paralysis of the legs two weeks after the operation and at the autopsy several months later the entire lumbosacral cord was found involved and its gray substance almost entirely destroyed. In the 9 cases of our table, there were 4 deaths from various causes, and the results in the remaining cases were commendable in only one instance, a case reported by Tschudi:

The patient, a woman, *aet.* 44, began, sixteen years before operation, to be troubled with diplopia and increasing weakness of the right leg. Eight years later, paralysis of the left leg and weakness of the left arm appeared suddenly, and a little later spasm in the lower extremities and left arm was added to the clinical picture. She could not stand except with support, and then only on the tips of the toes on account of the marked spasms of the feet. Bilateral nystagmus and bradylalia were also observed. The tendon and periosteal reflexes were increased; ankle clonus, Babinski and Oppenheim signs were present on both sides. There were no intension tremors; bladder and rectum were normal; the Wassermann reaction was negative, as was also the roentgenogram of the cervical and thoracic column. The spastic contractures, however, were so extreme that a rhizotomy was performed, the second, third and fifth lumbar and first sacral posterior roots being resected on both sides. One year after the operation the patient was able to walk, if supported on either arm; she also could sit normally with legs flexed at the knee and hip. Her general condition was excellent, and the patient seemed satisfied with the result of the operation. However, the bradylalia had increased, a slight scanning could be detected in the speech, and intension tremors were present, especially in the right arm.

The relief following section of the roots after *Pott's disease* was striking in the only case that has been brought to my attention. The operation was performed eight years after the initial symptoms appeared. In the course of time a kyphosis of the lower cervical and upper thoracic vertabrae developed, and to relieve the spasticity Tietze resected the third and fifth lumbar and second sacral roots. Five months after the operation the child was able to walk with the aid of crutches and could go upstairs without assistance.

As illustrated by reported cases, very aggravated forms of spasticity have been relieved by root section in cases of *traumatic paralysis,* but the recovery of voluntary movement has been disappointing, since a flaccid paralysis invariably remained after the spasticity disappeared.

After-Effects of Root Section

Always after division of the sensory roots there will be more or less pain and muscle soreness and these continue until the proximal stump of the root has undergone complete degeneration. During this period, which may last four or five weeks, passive movements may be painful and there may be some hyperesthesia. The spasticity will be more or less under arrest from the beginning, the involuntary flexion of the limbs disappears, and voluntary movements to a limited degree gradually return. The patient will be able to execute movements of certain muscle groups, as in flexion of the foot, of the leg or thigh, and these movements will not be attended with associated movements of the other extremities or trunk. A valuable index of the success or failure of the operation is the condition of the reflex of defense. The continuance of this reflex forecasts failure and its complete abolition is essential for success. Otherwise

the patient would be unable either to walk or stand. The maximum return of voluntary movements must not be anticipated until after the process of reëducation has been begun and persisted in for a considerable time. When the child has been more or less mentally defective beforehand, the influence of the operation in many cases is quite striking. Comparisons have been made of photographs before and after the operation and the change in expression is very noticeable.

Postoperative Management

Section of the posterior roots should not be undertaken for the relief of spasticity unless arrangements can be made for a thorough systematic course of exercises. Immediately after the operation sedatives should be given liberally to control the pain accompanying root degeneration. For children, I prescribe bromids at more or less frequent intervals, according to the amount of restlessness and discomfort, with occasional doses of paregoric when the pain is more acute, and for adults, bromids and Dover's powders. These are continued as long as the root pains persist. To correct deformities, plaster-of-Paris dressings are employed with the limbs in a position the reverse of the preëxisting deformity. Thus, the lower extremities should be in a position of abduction, outward rotation and extension, the feet in dorsal flexion. In the upper extremities, the arms should be adducted, the forearms extended and the hands extended and in supination. The plaster-of-Paris dressings must be continued in service even after the exercises have been begun and should not be discarded until voluntary movements have been restored.

The essential features of the postoperative management are massage and faradization, passive movements, mechanical and educational exercises. To restore tone to the muscles that were incapacitated by the spasticity, massage and faradization are of distinct benefit. Passive movements may be begun within a few days of the operation, more or less restricted at first, according to the amount of pain which they excite. The movements should at first be limited to single joints and afterwards extended to the entire limb. They may be practiced several times in the course of the day and should be continued until the patient is able to execute similar movements without assistance. During the bedridden period the passive exercises may follow a definite scheme (Clark and Taylor): (1) resistive hip extension and flexion and passive stretching of hip extensors; (2) resistive hip abduction and passive stretching of hip abductors; (3) resistive outward hip rotation; (4) passive flexion and extension of the foot and resistive movement in the same manner; (5) resistive foot inversion; (6) with bent knees, resistive knee separation; (7) sitting, hip and knee flexion and extension; (8) coördination of standing by placing foot forward and sidewise on command; (9) hands on hips and practicing

rising and sitting on command; (10) sitting with feet on floor and practicing foot in dorsal flexion, each foot separately.

Küttner has observed that there is a tendency for the contractures to return whenever there is any sensory irritation of the legs, such as may follow undue pressure or friction of the plaster-of-Paris dressings, decubitus or even the subsequent operations on the muscles and tendons. In cases of aggravated spasticity there is for a long while a tendency for the limbs to return to the original deformity, so that it may be necessary to continue the plaster dressings at night over a period of months. The educational exercises are all important and should gradually replace passive movements. They consist essentially in the frequent and deliberate repetition of selected movements and must be persevered in for a period of time measured in years rather than months. The exercises are not to be restricted to the limbs alone, but should include the trunk as well, since in walking, even in standing, the trunk muscles play an important rôle.

1. *Exercises in Bed*[2].—Before the patient is able to get up, certain trunk exercises may be executed in bed. These consist essentially in sitting up, lying down, and turning over. In sitting up, the back should not be arched or the legs flexed, and in lying down the tendency for the legs to fly up should be overcome.

2. *Exercises in Standing.*—Probably not for two or three weeks will the patient be able to undertake active exercises. For this purpose at first the perambulator will be found helpful. Later the child may be supported by an attendant, later still with canes and finally may stand alone. After the patient is able to maintain his equilibrium in standing by continued practice and training, he may then proceed to the third stage of the course, namely, exercises in walking.

3. *Exercises in Walking.*—In advancing one leg, the knee of the other should be extended, not flexed, to support the trunk, and the tendency for the trunk to incline toward the side of the advancing leg should be resisted. At first the child will need the support of two canes and as much attention should be paid to the supporting as to the advancing leg. The foot should not be raised at first too far above the floor, as it will be more difficult to maintain equilibrium. Later, however, freer movements of the leg should be encouraged, with greater flexion of the knee and hip joints, and the leg is carried forward with a swinging motion to counteract the tendency to adduction and inward rotation.

To obtain the maximum benefit from root resection in the restoration of voluntary movement, it may be necessary to remove some of the causes of restricted motion by tenotomies, tendon transplantations, myotomies and the like. Thus, for example, even though spasticity may have been relieved, a structurally shortened muscle may retard the restoration of voluntary motion. To overcome this, in selected cases tenotomies or

[2] These directions follow closely the régime prescribed by Küttner.

tendon lengthenings may be practiced to advantage, perhaps most frequently in Little's disease where the persistence of the lesion from birth has interfered with the normal muscular development. The indications for these operations are, however, equally positive in other types of spasticity accompanied by muscle shortening. For the best results, it is necessary not only to relieve spasticity but to lengthen the muscles. The muscles most frequently involved in these contractures are, in the lower extremity, the adductors of the thigh, the tensor fasciae latae, the flexors of the knee or hamstring muscles, the flexors of the ankle and adductors of the feet; in the upper extremities, the pectoralis major and latissimus dorsi, the pronator radii teres, the flexors of the hand and the adductor pollicis brevis.

Attention should be called to the fact that there exists in the minds of some a very decided feeling that there is as much to be said in favor of the accomplishments of *orthopedic operations* for the relief of spasticity as of resection of the sensory roots. My own feeling, however, is that these measures can never be considered radical in the sense that they will relieve the spasticity. They may for the time being serve to correct deformities the recurrence of which sometimes can be avoided by the continuous use of restraining apparatus, but if the spasticity be aggravated, the deformities must inevitably recur, whether or not tendons were divided or lengthened. There are those who disapprove, under any circumstances, of root section for these spastic cases, preferring the simpler orthopedic measures, and as one would expect, the majority of those holding these views are to be found among the orthopedic surgeons. We will not here enter into a discussion of the dispute between these two general lines of thought. Suffice it to say at this time that these minor correctional operations should not be considered equivalent in their results to division of the sensory roots. There is no doubt that there is a field for the practice of both methods, and that some discretion must be used in the selection of cases for one or the other of these general plans of procedure. For example, in cases of very minor severity, where the spasticity is confined to certain groups of muscles and where it does not seriously impede locomotion, the propriety of the minor operations upon the tendons and muscles should not be disputed. This distinction must always be borne in mind, however—that operations upon the muscles and tendons have this limitation and in this way are to be distinguished from operations upon the sensory roots, namely, that they are purely symptomatic procedures and, therefore, cannot possibly restore in the same way or to the same degree voluntary movement.

Naturally, in this work upon Surgery of the Spine and Spinal Cord, the operation upon the sensory roots, which has a firm physiological basis, is given foremost consideration, but I believe that other adjuvants for the desired results should be borne in mind. After the active spasticity

has disappeared through an interruption of the reflex arc, the muscles may be so shrunken and contracted from the previous constant spasms that they cannot assume their normal positions, and the restoration of voluntary motion will be possible only after the muscle has been stretched or released in some way. Indeed, it may be that in many cases the treatment must comprehend, not only the operation upon the roots, but also tenotomies, myotomies, osteotomies, arthrodeses and operations upon the peripheral nerves about to be described.

Peripheral Substitutes for Root Section

As a substitute for rhizotomy or supplemental to it, I want to refer at this juncture to several methods of combating spasticity by attack upon the peripheral nerves, and among these mention will be made of Stoffel's resection, Schwab and Allison's alcoholic injection and Spitzy's transplantation.

The principle of **Stoffel's operation** is based upon the fact that by resection of certain bundles in motor nerves the energy of the spastic muscles may be reduced proportionately and thus the equilibrium between the spastic and the antagonistic muscles restored. This operation has been made possible by anatomical studies in which it was found that the nerve bundles from individual muscles, when they unite to form a common trunk, do not intermingle with the others, but continue as separate and distinct bundles, and, what is of equal interest, occupy a reasonably constant position in the trunk. To relieve spasticity in a limited group of muscles, the nerve supply of these particular muscles may be isolated in the trunk by the use of faradic stimulation or by tracing these bundles from the muscle to the nerve trunk. When the proper nerve bundles have been isolated, they are resected for a distance of five or more centimeters. Sometimes the entire supply of the individual muscle is sacrificed, sometimes only a portion. To illustrate this let me cite examples for both the upper and lower extremities. In a case of flexor contracture of the knee, one has to deal with the biceps, the semimembranosus and to a less degree with the semitendinosus. In the sciatic nerve will be found, on its mesial side, the nerve bundles from the affected muscles. With the aid of the electrode the bundles for the biceps and semimembranosus are isolated and a portion of each resected (Fig. 278). Only one-third of the bundle to the semitendinosus is resected, or if it be a case of moderate severity, the nerve supply to the semitendinosus may be left intact. In the upper extremity, consider a case of flexor contracture of the forearm. The median nerve is exposed by an incision extending from the bend of the elbow to a distance of ten centimeters along the inner margin of the biceps muscle. The branches to the ulnar head of the pronator radii teres and the flexor

carpi radialis are isolated with an electrode and from five to seven centimeters of each resected (Figs. 279 and 280).

With painstaking thoroughness Stoffel has elaborated this technic for all the muscles of both upper and lower extremities most frequently involved in spasticity, and his anatomical dissections are liberally reproduced for the benefit of those who may want to repeat his operation.[3] The Stoffel operation requires on the part of any one who would practice it faithful and painstaking study of the minute anatomy of the nerves involved with special consideration for the topographical relation of the

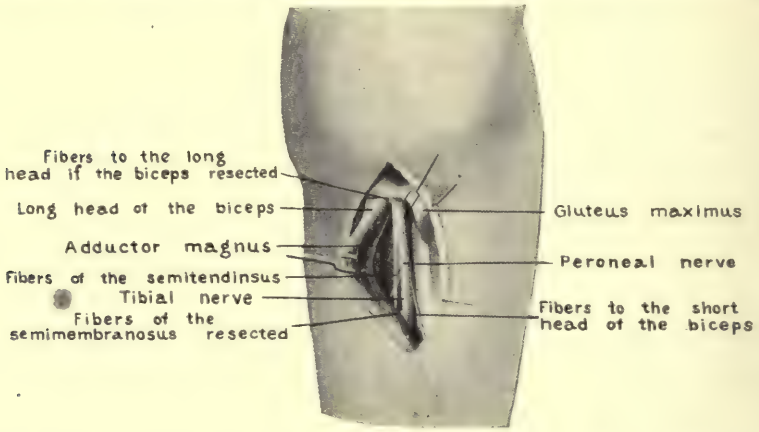

Fibers to the long head if the biceps resected
Long head of the biceps
Adductor magnus
Fibers of the semitendinsus
Tibial nerve
Fibers of the semimembranosus resected
Gluteus maximus
Peroneal nerve
Fibers to the short head of the biceps

FIG. 278.—STOFFEL OPERATION FOR SPASTICITY OF THE FLEXORS OF THE KNEE.
The fibers to the long head of the biceps and the semimembranosus have been resected.

muscle bundles in the nerve trunk. The working out of these anatomical relations has been accomplished at the expenditure of a great deal of time and patience, and unless one is thoroughly familiar with the details, he should not attempt either to practice or to comment upon the Stoffel method. I can speak somewhat feelingly upon the subject, because of the series of experiments carried on in my laboratory, consisting of careful anatomical studies on the lower animals and upon infant cadavers analogous to those which Stoffel made upon adults.

Partial resection of the nerves, as proposed by Stoffel, is applicable only in a very limited field. In the first place it does not replace the need of a root section or a tenotomy. It is really an auxiliary measure designed to master the spasticity in an individual muscle or a group of muscles with somewhat similar functions. When walking is hindered by spastic flexion of the toes as the foot comes in contact with the floor, the Stoffel operation finds an indication; especially in spasticity of the

[3] See Stoffel's monograph in the Orthopädische Operationslehre: Vulpius and Stoffel. 1913, Hft. ii, Stuttgart.

forearm, hand and fingers, where root section is of little benefit, Stoffel's operation may be helpful. Whatever may be its field of application, it certainly should not be practiced when the spasticity is diffuse, when

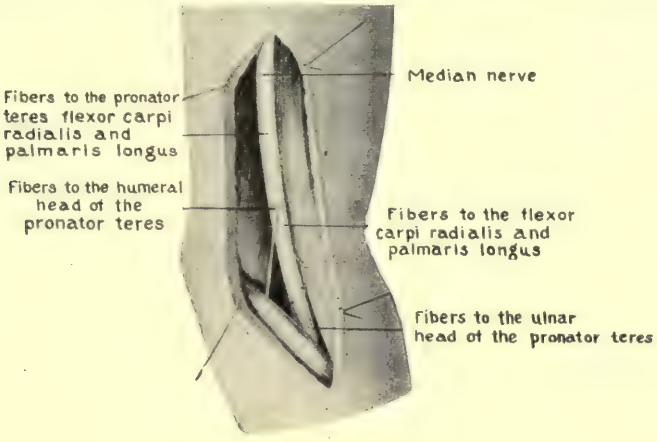

Median nerve
Fibers to the pronator teres flexor carpi radialis and palmaris longus
Fibers to the humeral head of the pronator teres
Fibers to the flexor carpi radialis and palmaris longus
Fibers to the ulnar head of the pronator teres

Fig. 279.

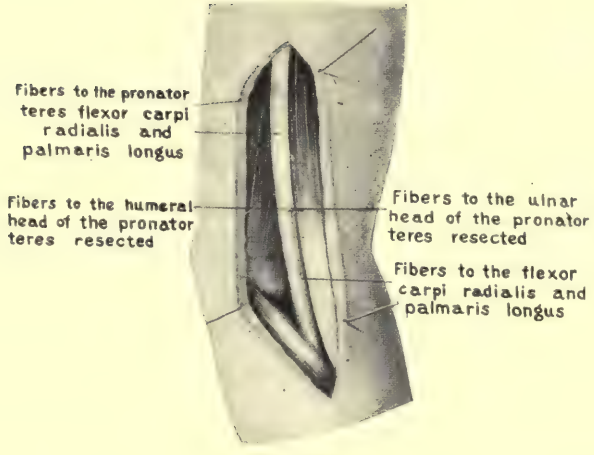

Fibers to the pronator teres flexor carpi radialis and palmaris longus
Fibers to the humeral head of the pronator teres resected
Fibers to the ulnar head of the pronator teres resected
Fibers to the flexor carpi radialis and palmaris longus

Fig. 280.

Figs. 279 and 280.—Stoffel Method for the Pronation Contractions of the Forearm.

Fig. 279.—Isolation of the fibers supplying the pronator teres, the flexor carpi radialis and the palmaris longus.

Fig. 280.—The fibers to the humeral and ulnar heads of the pronator teres have been resected. The fibers to the flexor carpi radialis and palmaris longus are still intact.

there is an associated athetosis or mental defectiveness, or when the lesion is progressive. What has been accomplished by the Stoffel method is a recital on a smaller scale of the results of root section. Stoffel himself has carried out his technic over a hundred times and, upon the basis of

a

b *c*

FIG. 281.—CASE OF NINE YEAR OLD CHILD WITH LEFT-SIDED HEMIPLEGIA.
(Stoffel case.)

a, Before operation, showing aggravated flexor contracture rendering the hand useless; *b*, after operation the return of active supination, as in placing the hand to the mouth; *c*, when extended, the hand does not assume position of flexion, but is maintained in extension.

this experience, unqualifiedly endorses it. He has been able to relieve spastic flexion and extension contractions of the forearm and hand, contraction of the fingers and thumb, adductor contractions of the thigh, flexion and extension contractions of the leg, equinovarus and contractions of the toes. His results were especially gratifying in the upper extremities where he found a wider field because operations upon the tendons were here so unsatisfactory. Where before the operation the arm was in the position of extreme pronation, after the operation voluntary supination was restored (Fig. 281). The flexor contracture of the hand was also permanently relieved in that the hand no longer assumed the position of flexion with each movement, but could be held extended. If the extensor tendons have been overstretched by years of flexor contracture, some time must always elapse before, through the persistence of active exercises, extensor function is restored. What was true of the flexor contractures of the hand was also true of the contractures of the fingers, but with this, as with other forms of treatment, great emphasis is laid upon the fundamental importance of the after care.

FIG. 282.—PHOTOGRAPH OF PATIENT BEFORE THE OPERATION IN A CASE OF CONGENITAL RIGHT-SIDED SPASTIC HEMIPLEGIA. (Guradze.)

The forearm is in a position of extreme pronation, hand flexed, thumb adducted.

By way of comparison I have reviewed the experience of others, including Kofman, Biesalski, Guradze, Hohmann and Bundschuh, and find that, though their experience has not been so comprehensive, the results were comparable with those of Stoffel. As an example of the possibilities of this treatment may be cited the experience of Guradze with a congenital right-sided spastic hemiplegia. The spasticity involved the pronator radii teres, the pronator quadratus, the flexor carpi radialis, the flexor carpi ulnaris, the palmaris longus and the muscles of the thumb (Fig. 282). The median nerve was exposed above the elbow at the inner margin of the biceps muscle. The proper bundles, chiefly on the radial and flexor aspects, including about three quarters of the diameter of the nerve, were isolated with an electrode, and three centimeters of these bundles resected. The patient could adduct and abduct the thumb, the wrist could be extended through an arc of 45 degrees, objects could be held in the hand and she was able to supinate the forearm sufficiently to support the head in the palm of the hand (Figs. 283 and 284). On the whole the function of the limb was very much improved.

FIG. 283.—SAME CASE AS IN FIG. 282, AFTER OPERATION. (Guradze.)

Photograph showing partial extension of the wrist and adduction of the thumb.

An impartial criticism of the Stoffel method should not omit some reference to the possibility of increasing the paralysis already present. Nicety of judgment is required, and this can be gained only by experience, as to the amount of any given nerve to be resected. If too little be resected, the antagonistic muscles are still uncontrolled; if too much, the resulting paralysis prevents the resumption of coördinate movements. Thus in an instance where too much was resected, the position of the hand was reversed from that of pronator flexion to that of supination and extension. Final judgment must be tempered somewhat by the possibility of nerve regeneration and consequent recurrence; under no circumstances should the result of an operation be considered final until sufficient time has elapsed for the nerve to regenerate, be it three months, six months, or a year, and only because in some instances improvement has been maintained over a year and a half has the operation been given any consideration. The mere fact that the Stoffel method does not deal with effects of shortened and contracted muscles is not a case in point, as in the after-treatment these obstacles to success may be met with massage, exercise, or tenotomies. Förster, although partisan to root resection, sees in the Stoffel technic a field of usefulness, particularly as an adjuvant to rhizotomy in overcoming spasticity of the fingers and toes, thereby restoring to the limb a wider range of unrestricted movements.

a *b*

FIG. 284.—SAME CASE AS IN FIGS. 282 AND 283, AFTER OPERATION. (Guradze.)

a, Photograph showing restoration of supination when the elbow is flexed; *b*, photograph showing ability to hold objects after the pronator spasticity has been relieved.

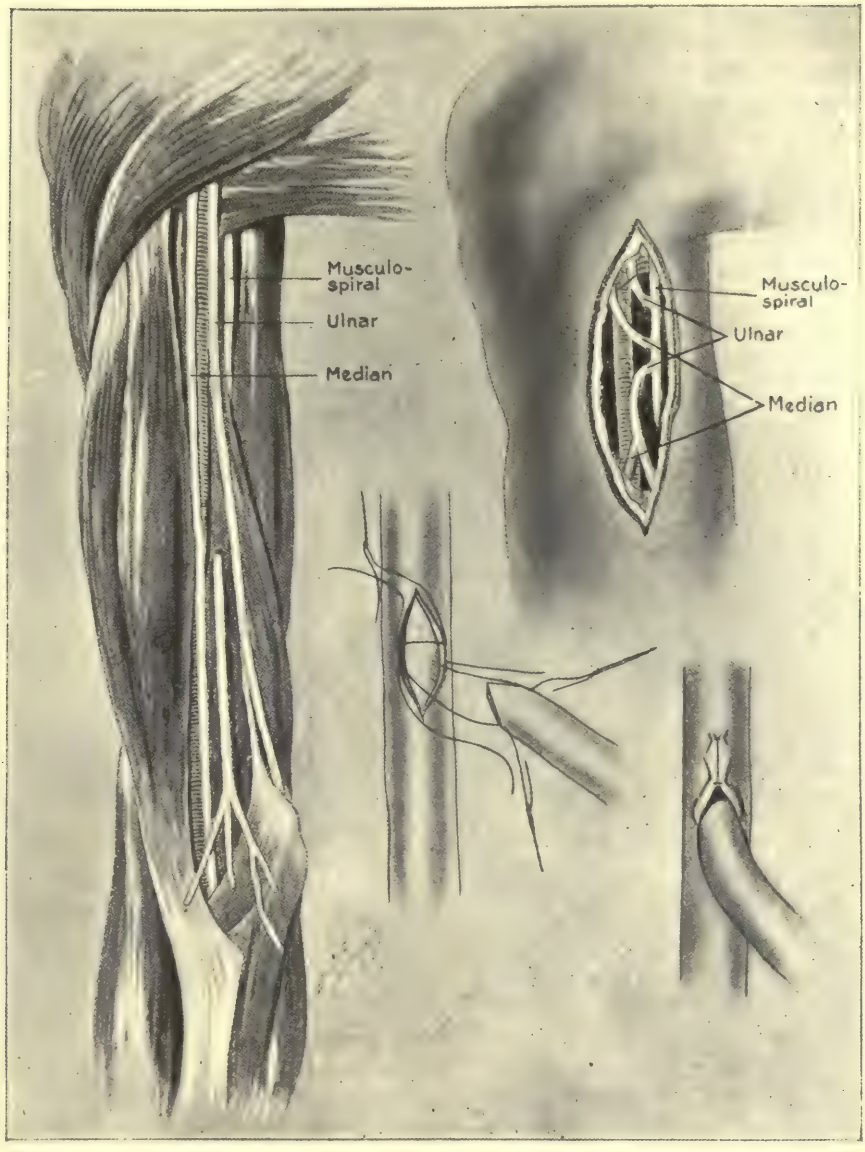


FIG. 285.—METHOD OF NERVE TRANSPLANTATION FOR RELIEF OF SPASTICITY.
Implantation of the proximal and distal ends of the divided ulnar nerve into the intact musculospiral. Implantation of the central end of the divided nerve into the musculospiral and the distal end into the ulnar nerve.

Some years ago Spitzy conceived the idea of controlling spasticity by transfer of the nerve impulses from the median to the radial nerve, hoping thereby to restore muscle equilibrium. As practiced by himself and others, the operation consisted solely in **transplantation** of about one-third

of the median nerve into the radial. The basic principle of this is unsound, because in so doing the sum total of the impulses could not be decreased. The nerves are anatomically very similar in function and continue intact from the anterior horns of the spinal cord. As the underlying lesion has nothing to do with the peripheral nerves and as there is no

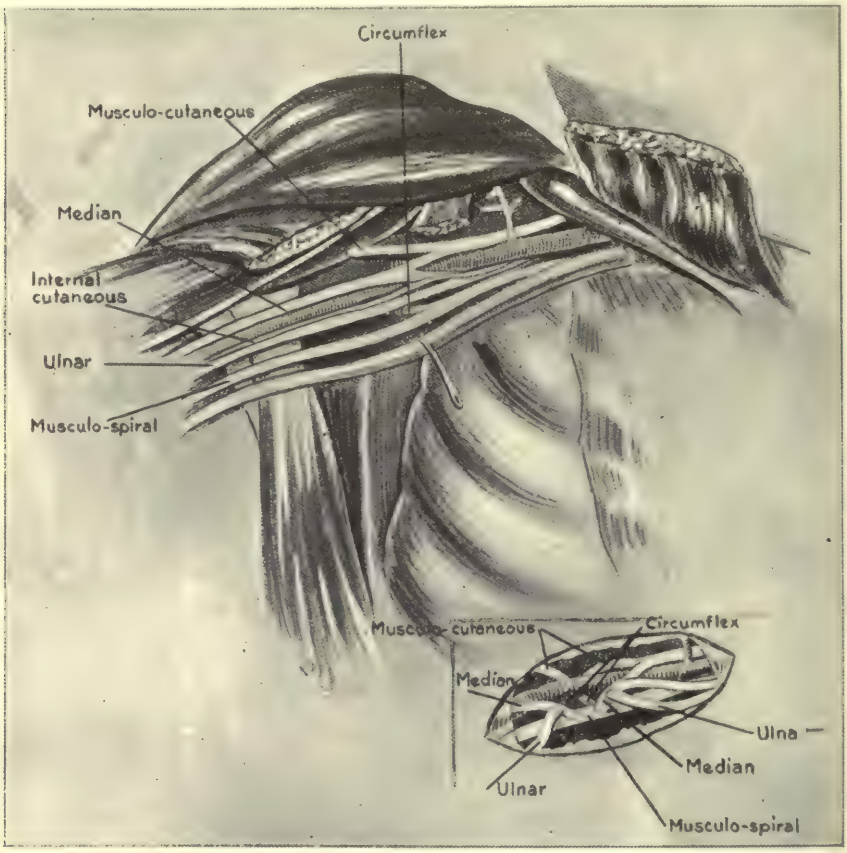


FIG. 286.—METHOD OF NERVE TRANSPLANTATION FOR RELIEF OF SPASTICITY.

To control the violent contractures of the biceps muscle, the central end of the musculocutaneous was sutured to the peripheral end of the circumflex nerve and the central end of the latter sutured to the peripheral end of the former.

interruption of the reflex arc, nothing can be accomplished. About the time that Spitzy made this proposal, I had occasion to observe in a case of aggravated athetosis the effect of the complete transfer of the flexor into the extensor innervation and *vice versa*. (Figs. 285 and 286.) The improvement that followed the operation was only transitory and was attributable to the paralysis resulting from the temporary withdrawal of the nerve supply from many of the spastic muscles. As soon as function

was restored by this physiological union of the nerves in their distorted distribution, the athetosis returned with its original vigor.

Alcoholic injection of the nerves supplying the spastic muscles, as advocated by Schwab and Allison, is worthy of note. The procedure is based upon the same principle as resection of the posterior roots and the peripheral neurotomy. Dr. Allison writes me that of the 28 cases operated on since 1911 the results have been perhaps a trifle better than in the earlier series because the patients had received more attention in the postoperative period.

Summary

The subject of root section or rhizotomy for relief of spasticity has been given more prominence than might at first sight seem warranted by its accomplishments. It must be conceded that the method is radical and the results not uniformly brilliant, but in the author's opinion, this physiological method of dealing with spasticity, now accepted by but a few and repudiated by many, will in the future be accorded a place, with a limited sphere to be sure, in the category of appropriate methods. The author has endeavored to place the subject before his readers conservatively; to make extravagant claims would be misleading. If the surgeon by misrepresentation were encouraged to resort to the operation ill-advisedly, the operation would soon be brought into disrepute. At this time the question is not whether root section is justifiable under any circumstances, but in what restricted sphere it is to be recommended. Outspoken opposition to the method comes chiefly from the camp of the orthopedists, but whether or not their opinions are accepted, I find their objections are for the most part theoretical and not the result of practical experience. Perhaps this is but natural, as neurological surgery, especially of the cerebrospinal system, is entirely foreign to the field where the orthopedist surgeon is at home, and he has wisely kept aloof from it. But their objections must be given full consideration and may be enumerated as follows:

(1) It is claimed that good results after rhizotomy have been obtained only by its sponsor, Förster. Equally good results have been obtained, however, by Guleke, Groves, Hunkin, Clark and others.

(2) It is claimed that the operation is too serious and the complications too many to warrant its acceptance. We admit the mortality is high, as it is in the early periods of all new operations of major grade, when its limitations are not understood and its sphere not accurately defined. Proper selection of cases and greater nicety in technic will lower the mortality.

(3) It is claimed that by minor procedures, tenotomies and the like, the results are equally good, and that what has been accomplished by root section is to be attributed not to the practice of that operation but to

the minute and conscientious attention to details in the after treatment which often includes tenotomies. The vulnerability of this line of argument is patent; tenotomy and rhizotomy are not comparable, in that tenotomy affects only muscle shortening, while rhizotomy relieves the active spasticity upon which tenotomy can have no influence. Rhizotomy does not preclude the possible benefits to be derived from tenotomy. In point of fact, tenotomy is essential to the recovery of function, for even after spasticity is relieved, freedom of motion is further restrained by muscle shortening.

(4) It is claimed that, admitting the ultimate propriety of rhizotomy, inasmuch as tenotomy will be required in most cases under any circumstances, it, in conjunction with other auxiliary methods, should be practiced before, not after, the major operation. By this sequence, it is said, the need for further intervention may be avoided in certain instances. At first sight this argument seems reasonable and not to be controverted. While the author has no objection to this proposed reversal of order, he would remind the reader that little is to be gained by tenotomy until spasticity has been relieved sufficiently to make it possible to institute passive and active exercises.

To safeguard rhizotomy from injudicious practice the following limitations should be strictly observed: The operation should not be undertaken unless the operator has both facility and intention of giving the patient continuous treatment for several months or years if need be; for the time being it should not be used for spasticity of the upper extremities; it should not be used in feeble-minded or epileptic subjects, nor in those in a state of impoverished nutrition forbidding a major undertaking; it should not be used in multiple sclerosis, in syphilitic lesions or in any kind of a progressive lesion. Moreover, it should not be used in cases of mild degree nor in spasticity involving only individual muscles or groups of muscles. It should be reserved for the spastic diplegias where there is a residuum of muscle tissue on which to build and where the spasticity is severe enough to be disabling. Little's disease represents these conditions more often than any other.

The Stoffel operation, though less well established and not so fully elaborated with respect to technical detail, may with propriety be given a trial in spastic conditions of the hands and the toes. The underlying principle must be thoroughly understood and the operator must be familiar with the topographical arrangement of the constituent branches in the nerve trunk. Finally, tenotomy alone or occasionally a tendon transplantation must be used as an auxiliary measure whenever the range of voluntary motion is restricted by muscle shortening.

OPERATIONS FOR THE RELIEF OF GASTRIC CRISES IN TABES DORSALIS

Section of the posterior roots has been applied during recent years in the treatment of still another condition, namely, the visceral, particularly the gastric, crises of tabes. The expansion of the field of rhizotomy in this direction was first suggested by Förster in 1908, on the ground that the severe pain and symptoms of sensory irritation, such as marked hyperesthesia in the epi-, meso- and hypogastrium with exaggeration of the abdominal reflex, are caused by irritation of the cell bodies of the sensory sympathetic fibers of the stomach. These pass from the celiac plexus in the splanchnic major nerve to the cord through certain of the posterior thoracic roots. Under this hypothesis, the crises should cease after the sensory pathway from the stomach has been intercepted by the severance of the posterior roots involved. Although this does not represent our ideas of the exact physiological pathway of afferent impulses to the spinal cord, yet, as can be seen in the physiological discussion (*vide* p. 120), there is agreement in that eventually these fibers enter the seventh, eighth and ninth posterior thoracic roots. The first operation of this kind was performed in 1908 by Küttner upon one of Förster's patients. A man, 47 years of age, had suffered for six years from gastric crises, characterized by severe pain and vomiting. All other forms of treatment had failed, and at the time of the operation he was greatly emaciated and addicted to the use of morphin. Following bilateral section of the sixth to the tenth posterior thoracic roots, the pain and vomiting ceased; the patient died of phthisis five months later.

Since that time the operation has been done repeatedly with varying degrees of success. We have inquired into the results of the 73 cases in which section of the roots was performed, and find that 14 are recorded as cured, 31 as improved, 6 as temporarily improved, and 5 as unimproved. Of the 16 deaths, 10 were operative deaths; of the remaining 6 cases, 3 were improved up to the time of death (Table VII, p. 717). Considering the desperate condition of these patients, prostrated, emaciated, victims of morphin, and often suicidal in intent, it is at least encouraging to note that more than half of them have been either partially or entirely relieved of the unbearable pain and incessant vomiting. Indeed, a sufficient number of cases has been reported in which section of the posterior thoracic roots has been followed by permanent relief from pain and vomiting, to render us hopeful at least as to the efficacy of rhizotomy.

Not all cases of gastric crises are responsive to rhizotomy. Of course, the pain of an organic lesion of the stomach is not under discussion, but we must discriminate between the crises due to irritation of the splanchnic afferent system and those originating in pneumogastric irritation. The

researches of Head, of Müller, of Neumann, of Eppinger and Hess and others, have uncovered a wealth of information touching upon the innervation of the stomach that must be drawn upon in this process of differentiation. The stomach is supplied by motor and secretory fibers from the pneumogastric nerve, representing the central nervous system, as well as by sympathetic fibers, the splanchnic afferent system passing through the posterior thoracic roots. Therefore, while the typical form of gastric crisis manifests itself in pain, hyperesthesia, and exaggerated abdominal reflexes, and later by vomiting and hypersecretion as secondary phenomena, there appears to be another type which is caused by irritation of the pneumogastric nerve. In the latter, we find no pain or hyperesthesia, but rather extreme nausea and vomiting. Upon the surface, therefore, it would seem as though we should exclude as unsuitable for section all cases in which pain and hyperesthesia are lacking. For those cases of pneumogastric origin, Exner recommended a subdiaphragmatic vagotomy, and Küttner has been bold enough to attempt section of the vagus between its exit from the medulla and the jugular foramen. The latter is sound in theory but ominous in practice.

By continued study of the end results of section we may be able to decide not only as to the cases appropriate for this method of treatment, but also as to certain points in the technic about which there is still some controversy, for example, as to how many roots shall be cut, or whether the section shall be performed intradurally or extradurally. Several other procedures, notably, avulsion of the intercostal nerves and removal of the ganglia on the posterior thoracic roots, have been devised and carried out with varying results. These are based upon the same principle as section of the posterior roots, and we shall discuss later their relative merits.

Clinical Manifestations of Gastric Crises.—While the clinical picture of tabes dorsalis is more or less varied, particularly as regards the sequence in the appearance of symptoms, we are here concerned chiefly with the sensory phenomena characterized by paresthesias, hyperesthesias, and severe "lightning" pains in various parts of the body, particularly in the limbs, or by the development of "crises" of various organs, especially of the stomach. In addition to the gastric crises, intestinal and rectal crises are sometimes observed, less frequently crises of the larynx, pharynx, bladder and urethra, and still more rarely cardiac and genital crises. In a series of 174 cases of tabes, crises of one form or another were the first symptom in 18 and were present at some time in 58 cases (Starr). It would take us too far afield to dwell in detail upon the various kinds of crises. Suffice it to say that tabetic crises in general possess three common characteristics: sensory irritation phenomena, such as manifest themselves in the form of pain, hyperesthesia, and special organ sensation; motor phenomena in the affected organ; and finally, certain secre-

tory disturbances. The first of these, sensory irritation, is the primary disturbance; the motor and secretory phenomena are secondary and of reflex origin.

Gastric crises are by far the most frequent. Out of 211 cases of tabes, Fournier found that this was the cardinal feature in 15; Erb found that it appeared first 10 times in 400 cases. In 456 cases of tabes in Starr's clinic, gastric crises appeared at some time in the course of the disease in 49 cases. Although cases of tabes in which gastric crises probably were present had been previously described by Romberg, Grube, Duchenne and others, we owe our first intimate knowledge of this phase of the disease to Charcot's classic description in 1868. The gastric crisis is often one of the earliest manifestations of tabes, and it may increase in severity until the patient's life is menaced by the excessive denutrition and the morphin habit to which he is almost inevitably forced.

The typical gastric crisis begins suddenly with severe pain in the epigastrium, radiating sometimes to other parts of the abdomen or to the back, sometimes to the entire body. This pain, lancinating or boring in character, is usually accompanied by a marked degree of hyperesthesia, beginning in the epigastrium and extending girdle fashion about the body. There is occasionally some anesthesia in the extremities, as in a case upon which I recently operated.

Case of severe gastric crises in a man forty-five years of age. Operation: laminectomy and section of four pairs of thoracic roots, the last leaving the cord on a level with the spinous process of the eighth thoracic vertebra. The vomiting and pain had been relieved when the patient left the hospital.

The patient, a man *aet.* 45, was admitted to my service at the University Hospital, May 1, 1913 (File No. 23730). He was a miner and used alcohol to excess. He had a chancre twenty-three years before and at once began treatment with mercurial inunctions and potassium iodid; eleven years before he began to have lightning pains in the lower extremities, and two years before admission to have attacks of burning pain in the epigastrium accompanied by persistent vomiting and extreme nausea. The hyperesthesia was most marked on the left side of the epigastrium, and there was a peculiar burning, creepy sensation which radiated upward over the thorax. There was also numbness in the upper extremities and later in the lower. The attacks usually lasted a week and appeared at intervals varying from a few days to several weeks. Ten months prior to admission, July, 1912, a diagnosis of tabes was made and specific treatment instituted. In the following months the attacks became more frequent but of shorter duration.

Physical Examination.—The patient was a poorly nourished individual. The skin showed no eruptions or pigmentations. The sclera were clear, but the pupils were unequal and did not react to light or accommodation. The upper teeth were gone. The neck showed no pulsations or glandular enlargements. The chest was fairly well proportioned; expansion was good and there was no sign of any lesion in the lungs. The heart sounds were regular and of good quality. The abdomen

was flat with no areas of tenderness or palpable masses. The patellar reflexes were absent, but gave slight response upon re-inforcement.

Laminectomy, May 3, 1913. Endotracheal anesthesia. Removal of the spinous processes of the fourth, fifth, sixth, seventh and eighth thoracic vertebrae and the laminae of the fifth, sixth, seventh and eighth. Traction sutures were introduced after the dura was opened. Identification of the roots was somewhat difficult on account of the adhesion of the pia-arachnoid. The first pair of roots were cut opposite to what corresponded to the tip of the spinous process of the fourth thoracic vertebra. Altogether five pairs of posterior roots were cut, the last pair leaving the cord at about the spinous process of the eighth thoracic. It appeared as though the roots on the left side were larger than those on the right. Cotton saturated with 4 per cent stovain solution was applied to the cord and roots above the level of the point at which they were divided. Before closing the wound adrenalin chlorid was applied to the stump of one root to control bleeding; otherwise the wound was perfectly dry. The wound in the dura was closed with continuous suture, the erector spinae muscles with silkworm gut splint sutures, the sheath of these muscles and the intravertebral aponeurosis with continuous catgut sutures and the skin with interrupted silkworm gut. The vomiting and pain were relieved and the patient was discharged from the hospital four weeks after the operation.

In addition to pain, extreme nausea and exaggeration of the epigastric reflex, causing tonic contraction of the abdominal muscles, characterize this stage of the crisis. All of these disturbances may appear some time before the motor irritation phenomena manifest themselves by the almost incessant vomiting which continues for several hours or several days, and leads to great prostration. During this time food is rejected as soon as it enters the stomach. Starr describes a case in which this constant vomiting continued for ten days, so that finally life had to be sustained by means of nutritive enemata. We find that the vomiting is accompanied by increased nausea and weakness, and often by vertigo, palpitation, and a feeling of compression in the upper part of the thorax. The secretion of bile is so increased that large quantities are rejected together with mucus. The bladder and rectum may be involved to a greater or less degree, and both blood pressure and temperature continue elevated throughout the crisis. The patient rapidly loses weight, becomes extremely depressed, and in some cases even sinks to a stuporous condition.

The termination of the typical gastric crisis is often as sudden as its onset. It may last only a few hours, or it may continue for several days and even weeks. The frequency of the attacks varies greatly; in most cases they tend to become more frequent and more severe during the course of the disease until there are few days completely free from crises, while in other cases they appear only at irregular intervals and later disappear entirely. It must be borne in mind, however, that these crises are completely lacking in many cases of tabes. Furthermore, gastric crises may assume various atypical forms, according to the predominating phase of the symptom-complex. There are pure gastralgic types in which the

pain is not accompanied by vomiting; on the other hand, the vomiting and nausea may constitute the principal features and completely overshadow the pain and hyperesthesia. It may be noted in passing that gastric crises are more common in the male than in the female, and develop more frequently between the ages of forty and fifty (Table IV).

TABLE IV

THE AGE AND SEX INCIDENCE OF 73 CASES OF GASTRIC CRISES WHERE SECTION OF THE POSTERIOR ROOTS HAS BEEN PERFORMED

Sex	20–30 Years	30–40 Years	40–50 Years	50–60 Years	Over 60 Years	Age Not Stated	Total
Male	4	14	17	1	2	6	44
Female	1	1	10	2	..	1	15
Not stated	..	3	..	..	..	11	14
TOTAL	5	18	27	3	2	18	73

Diagnosis of Gastric Crises.—Whenever a diagnosis of tabes has been made before the appearance of the crises, there is little doubt as to their origin, especially if they conform to the usual type. It frequently happens, however, that the crises appear before the lesion of the nervous system is even suspected. The pain and hyperesthesia of gastric crises may simulate, though only superficially, the pain of organic diseases of the stomach or gall bladder, as in gastric ulcer or cholelithiasis. Thus patients have been subjected to needless abdominal operations before the true nature of the condition was recognized. In our table of 73 cases there had been a gastro-enterostomy in four instances, a cholecystectomy in two, a cholecystostomy in one and a negative exploration in two. A striking example of shortcomings in diagnosis was observed in one patient who had been obliged to submit to four operations for a supposed stenosis of the pylorus, three gastro-enterostomies and one entero-anastomosis. There is no excuse for such mismanagement. It should now be possible to differentiate gastric crises from such other conditions as cause severe pain and hyperesthesia in the abdomen and thorax. Once the diagnosis of tabes is established, the possibility of error is reduced to a minimum. In doubtful cases, therefore, inquire into the Wassermann reaction, the condition of the eyegrounds, pupillary reactions, the patellar reflexes and other signs suggestive of tabes. *Whenever paroxysms of gastric pain and vomiting are accompanied by marked hyperesthesia in the lower part of the thorax and abdomen, and an exaggerated epigastric reflex, the possibility of gastric crises should always be borne in mind.* Tabes must be eliminated absolutely before an abdominal operation be even considered. With the present day facilities for accurate diagnosis, the treatment of

the tabetic patient for chronic gastritis, hyperchlorhydria, and the like is a travesty in the practice of medicine.

It would certainly seem as though there should be no difficulty in distinguishing between the pain of tabetic crises and the pain incident to duodenal or gastric ulcer, to biliary or renal colic. That mistakes in diagnosis have been made and exploratory operations performed under the misinterpretation of signs and symptoms may be offered in evidence that in some instances at least the clinical findings may be confusing. The sharp stabbing pain, coming on sometimes without warning, accompanied or followed by vomiting, occasionally with signs of collapse, suggests perforation of a peptic ulcer, either of the stomach or the duodenum. If this occur in a patient with a suspicious "ulcer" history, and if there develop soon after the onset of pain, which is greatest to the right of or in the median line of the epigastrium and often referred to the back, board-like rigidity of the abdomen and other signs of a spreading peritonitis, this clinical picture should never be confused with that of a tabetic crisis. For uncomplicated ulcer there are two reliable means of establishing a diagnosis, the history and the roentgenogram. The history of the ulcer case has certain earmarks that give it individuality, notably, chronicity, periodicity, attacks with remission and pain at definite relation to meals. The pain of duodenal or gastric ulcer is not shooting or lancinating, but dull and boring. There is no hyperesthesia and no exaggerated abdominal reflexes. Vomiting is never excessive and persistent nausea unheard of. In from 80 to 90 per cent of cases, if there be any doubt, the diagnosis can be made from the roentgenogram. The gastric analyses may add confirmatory evidence, but are not to be relied upon.

When we come to the pain of biliary colic there is no excuse for falling into error, unless it be because the pain is very intense. In a case later referred to me this mistake had been made and an exploratory operation performed because pain of an intense character, more so on the right than on the left side, had been referred to the level and region of the gall bladder. Cholelithiasis is a disease mostly of women; tabes, mostly of men; in the paroxysms of biliary colic there are signs of localized tenderness over Mayo-Robson's point; in tabes there are none. In biliary colic the gall bladder may be palpable, there may be rigidity of the right rectus, pain is referred often to the shoulder blade and is relieved by vomiting. The attacks of biliary colic come on without warning, usually at intervals of several months, last perhaps a few hours, possibly a few days, but between the attacks the patient suffers from indigestion with a train of symptoms attributable partly to the toxic influence of an infected gallbladder and partly to the reflex action upon the secretion and motility of the stomach.

There is no necessity for going into the symptomatology and differential diagnosis of acute abdominal catastrophes, such as acute pancreatitis,

intestinal perforation or obstruction. The diagnosis of a gastric crisis need be considered only after these more acute and threatening conditions have been eliminated.

Pathogenesis.—That the gastric crisis of tabes is a phenomenon purely of nervous origin must be accepted. Organic lesions of the stomach may be excluded as etiological factors, first because the stomach has been found normal or approximately so in nearly all cases that have come to autopsy, and secondly because no definite and constant change in the gastric contents has been demonstrable during the attacks. Attention has been directed already to the fact that the sensory fibers of the stomach pass through the sensory sympathetic system to the spinal cord. According to the researches of Head, and more recently of Laignel-Lavastine and Eppinger and Hess, these pass from the stomach to the celiac plexus, thence by way of the semilunar ganglion, the splanchnic major nerve, and the rami communicantes to the seventh to ninth posterior thoracic roots, and finally to the cord itself. Förster and others are now of the opinion that the fifth and sixth as well as the tenth, eleventh and twelfth thoracic roots are concerned, possibly even the first and second lumbar. This opinion as to the pathways of afferent impulses has gained much headway from the fact that it is constantly quoted by any one writing on the subject, but Allen, who questions the existence of afferent pain fibers from the stomach in the pneumogastric nerve, gives a very different route, although the final destination to the posterior ganglia of the seventh, eighth and ninth thoracic segments is the same (*vide* p. 130). The question is not whether the crises are organic or functional in origin, but rather whether they are due to a lesion of the vagus or the sympathetic nervous system, and if the former, whether peripheral or central.

The increased abdominal reflexes and extreme hyperesthesia in the region supplied by the seventh to ninth posterior thoracic roots point to an irritation of these posterior root fibers as the causative factor. The fact that the hyperesthetic area is often more extensive than the peripheral distribution of the seventh to ninth thoracic roots should not be regarded as contradictory evidence, inasmuch as in many instances the tabetic process is not limited to these three roots. The disappearance of the finer myelinated fibers of the sympathetic nerves in gastric crises, a point first brought out by Roux, and the appearance of an herpetic eruption over the area supplied by the sixth to ninth posterior thoracic roots, as in Siding's case, are strongly on the side of the sympathetic origin of the disease. Moreover, the physiological researches of Müller and of Neumann would seem to eliminate the vagus as a factor in the sensory innervation of the stomach. This nerve is frequently found intact in cases of gastric crises, the atrophy of the vagus nucleus is far from constant and, as Cade and Leriche have brought out, the bulbar symptoms may easily be accounted for by a transmission of the irritation to the medulla. This

corresponds to Allen's ideas concerning the relation of the vagus to the sympathetic in the lower esophagus and stomach (*vide* pp. 127-128).

That there are cases of so-called gastric crises of pneumogastric origin must go unchallenged, but in these, pain, hyperesthesia and exaggerated epigastric reflexes are lacking. These are the cases associated with the laryngeal crises and the cardiac disturbances, and possibly with hyperesthesia in the trigeminal distribution if it be true, as Head would have us believe, that the trigeminal fibers supplying the temporal and parietal zones of the head make their exit from the same bulbocervical segment as the fibers of the vagus.

Granting that the vagus plays a part in the pathogenesis of certain forms of gastric crises, there is still difference of opinion as to whether the lesion is situated near the nucleus of the vagus in the medulla or in the peripheral portion of the nerve. In 1880, Buzzard found sclerosis about the vagus nucleus in the medulla in tabes, and Oppenheim, Landouzy, and Déjerine have reported atrophy of this nucleus under similar conditions. The laryngeal spasm, dyspnea, dizziness and dilatation of the pupils accompanying some of the crises further support the theory of the central rather than peripheral origin.

Heile has suggested the possibility of differentiating between the cases of sympathetic and those of pneumogastric origin by means of an epidural injection of adrenalin or atropin into the vertebral foramina. If the pain disappear temporarily, it is evident that we are dealing with a case of sympathetic origin in which the painful sensations are conducted to the cord via the rami communicantes.

Our conception of the pathogenesis of gastric crises might be stated somewhat as follows: in considering this much disputed question we must not lose sight of the fact that we are here dealing with a reflex, and it is altogether logical to assume that when, as in the majority of cases, the afferent limb of this arc, the sympathetic side, is affected, we have a picture in which the sensory symptoms predominate, with the possibility of accompanying motor symptoms through a transmission of impulses in the medulla. But when the efferent limb or the pneumogastric system is at fault, we would postulate a picture in which motor and secretory phenomena would be the chief manifestations. The idea of a purely efferent system being affected in tabes is no new concept, an example of which can be found in Allen's report of swollen axis cylinders in the oculomotor nerve in tabes and pseudotabes with Argyll-Robertson pupil.

Treatment of Gastric Crises.—The intensity of the pains in gastric crises and their unyielding response to commonplace sedative remedies probably account for the numerous methods, numerous as they are varied, which surgeons and physicians have devised for their control. For convenience sake, we will first take into consideration non-operative meas-

ures, and of these mention will be made only of antiluetic remedies and alcoholic injections.

It is to be assumed that ANTILUETIC TREATMENT, and more particularly salvarsan or salvarsanized serum, will have been applied in every instance before consideration is given to any other measures, and especially to any major surgical operation. From the results in his own practice, Allen speaks enthusiastically of salvarsan therapy, and his experience emphasizes the injunction that no thought of surgical treatment should be entertained until this treament has been tried and failed. Stewart has reported satisfactory results in a series of eleven cases. One also must not lose sight of the fact that tabetic crises may disappear spontaneously in the evolutionary process of tabes when the degeneration of the roots is complete.

ALCOHOLIC INJECTION of the posterior root ganglia has been proposed by Chiasserini, who, from his studies on dogs and cadavers, declared it feasible to interrupt the reflex arc by injecting alcohol into the spinal ganglia. Positive results are promised even though the alcohol does not penetrate but merely surround the ganglia. While Chiasserini has never applied this remedy to the living subject, he assures us that his observations upon the living animal have demonstrated its effectiveness, and upon the cadaver its feasibility. While I am not prepared to endorse this method, the suggestion appeals to me as the only procedure other than rhizotomy worthy of consideration and demanding further investigation. In the first place the results of alcoholic injection upon the central ganglia are known to all those who have had to deal with trigeminal neuralgia. In this form of neuralgia, equal in intensity to the pain of gastric crises, the injection of alcohol into the Gasserian ganglion or its several divisions in immediate proximity, affords in many instances absolute relief, although usually for only a limited period. The same measure of relief should follow effective injection of the spinal ganglia, and if the method of injection be not too difficult to master, I can foresee in alcoholic injections a field of usefulness in the treatment of perhaps the milder forms of gastric crises, if not all cases, in which a formidable operation is contra-indicated for one reason or another. In his operations upon the dog, Chiasserini exposed the ganglion before injecting it; while in his work on the cadaver he attempted to reach the ganglion without any preliminary operation, although he states that the results will be more certain if the intercostal space be exposed by a longitudinal incision and the muscles displaced.[4] After the injection (endo- or periganglionic) of alcohol (70-80-90 per cent) into the spinal ganglion of the dog, varying in quantity from a few drops to about 3 c.c., the following changes were observed: (a) In the spinal ganglia a general cellular degeneration, from a minimum

[4] For a complete description of the technic for injection of the spinal ganglia as carried out in my clinic (*vide* p. 637).

(chromatolysis, obliteration of the endocellular reticulum) in recent cases, in which the injections were endoganglionic, to a maximum (total chromatolysis, destruction of the nucleus, the cells being reduced to a mere shadow), when a certain amount of the alcohol penetrates into the ganglion; degenerative changes in the endoganglionic fibers; a direct paracellular infiltration; a tendency to connective tissue proliferation. (b) In the spinal roots and in the mixed nerve trunk there was more or less degeneration of the posterior fibers and less constantly degeneration of the anterior fibers. (c) Within the ganglia, a circumscribed connective tissue proliferation, with involvement of the dura.

If the passageway of afferent impulses from the sympathetic lie in the posterior root, as is generally conceived, the reasonableness of this method is quite evident, but if, as some have held, the passageway be very largely *via* the efferent root, which seems paradoxical, this method would be of no avail. But at the present time the latter conception so lacks confirmation, that we must grant that injection of the posterior root ganglia, like other procedures on the posterior roots or their ganglia, is sound in theory, and may become one of the methods of choice in the future.

Operative Methods in Gastric Crises.—In order not to be misunderstood, I will repeat for the sake of emphasis, that the consideration of rhizotomy or any major operation is to be reserved for the grave forms of gastric crises that do not respond to antiluetic treatment or to any other non-operative measure. With this understanding, I take up for discussion and review the several surgical procedures that have come to my attention. When assembled they present a formidable array:

I. Operations based upon the theory of interruption or conduction of sensory sympathetic fibers.

1. Stretching of the solar plexus (Jaboulay, 1900).
2. Intradural rhizotomy (Förster, 1909).
3. Extradural rhizotomy (Guleke, 1910).
4. Extraction of the intercostal nerves (Franke, 1910).
5. Chordotomy (Schüller, 1910).
6. Extradural gangliectomy (Sicard and Desmarest, 1912).
7. Ligation of both anterior and posterior spinal roots (Sauvé and Tinel, 1913).

II. Operations based upon the theory of interruption of the vagus.

1. Peripheral vagotomy (Exner, 1911).
2. Resection of vagus near the medulla (Küttner, 1913).

For purposes of discussion, I will admit a dual pathogenesis, a tabetic crisis of sympathetic and one of vagus origin, and I will take it for granted that the operations which have for their object the interruption of the sensory sympathetic fibers will be practiced only when pain is the pre-

dominant feature of the crises; and that the operations which have for their object the interruption of the vagus impulses will be practiced only when vomiting and hypersecretion without pain are the conditions demanding relief. Let it be understood, therefore, that all cases without pain should be regarded as unsuitable for an attack upon the sympathetic system.

Proceeding upon this hypothesis, I will take up first the operations upon the sympathetic system, in which are four points of attack: (1) the solar plexus; (2) the intercostal nerves; (3) the posterior root ganglia, and (4) the posterior roots. In 1900 Jaboulay, in the dissertation of his pupil Termier, stated that gastric crises might be relieved by *stretching the solar plexus,* a procedure which he had carried out twice in cases of severe gastralgia with satisfactory results, but it was not until 1906 that this operation for the relief of gastric crises was practiced by Vallas. It was Jaboulay's thought that even though the lesion might be in the roots, the desired result might be obtained by attacking the peripheral rather than the central portion of the sympathetic. This is the hypothesis. What are the results? We have been able to find records of but ten operations in which the solar plexus was stretched. In one of this number there was complete relief for two months and a half. In the remaining nine there was almost immediate recurrence. In every one of the five cases in which the solar plexus was stretched by Leriche there was a recurrence within four or five weeks. Delbet and Mocquot report immediate recurrence in their three cases. The most that can be said of Jaboulay's suggestion is not encouraging. The longest period of relief, as pointed out, two months and a half, was obtained by Vallas in his initial experience. His patient was 41 years of age and had been suffering for six years from both vomiting and pain. The attacks lasted three or four days and recurred each month.

The exposure and stretching of the solar plexus is not a difficult procedure; that is the best that can be said of it. Through an upper abdominal incision the stomach is exposed and the pyloric portion displaced downward; the gastrohepatic ligament is retracted and the aorta exposed. The guide to the solar plexus is the superior mesenteric artery, which is given off from the aorta a centimeter below the origin of the celiac axis. The solar plexus surrounds both the celiac axis and the root of the superior mesenteric artery. The plexus may be further identified by the semilunar ganglia, situated on either side of the plexus. The isolation and exposure of ganglion and plexus are accomplished by blunt dissection, stripping the roots of the celiac axis and the superior mesenteric artery of the loose cellular tissue. Originally Jaboulay proposed stretching of the plexus; later Leriche divided the branches of the celiac axis and removed both ganglia.

Continuing the discussion of sympathetic intervention centralward, I

turn to Franke's suggestion of *extracting the intercostal nerves,* which he proposed as a substitute for rhizotomy to the German Surgical Association at its annual meeting in 1910. Förster's operation was, he thought, attended with too great risk. The procedure did not at that time attract much attention, but it has since been given recognition. It was Franke's original contention that extraction of the intercostal nerves was easier and simpler than rhizotomy and that the results were equally good, if not better. Having had no personal experience with this method, since I have much greater confidence in rhizotomy, I refer the reader to the ex-

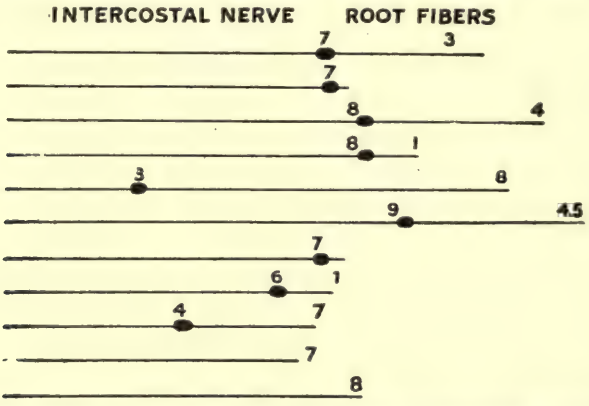


FIG. 287.—DIAGRAMMATIC REPRESENTATION OF ELEVEN INTERCOSTAL NERVES ACTUALLY REMOVED BY THE FRANKE METHOD FOR RELIEF OF GASTRIC CRISES IN TABES DORSALIS. (After Leriche.)

In two cases ganglia were left behind.

perience of others. This includes some 13 cases collected by Sauvé and Tinel. Two of the patients died, one from a purulent pleurisy (Franke's case), and one from a double pneumothorax (Sauvé and Tinel's case). Of the surviving cases, two had immediate recurrence, three later recurrence, five were reported as "cured," but the interval of relief not designated, and one case has been reported free from recurrence eleven months after the operation. In passing judgment upon this operation, although the mortality cannot be ignored, too much emphasis should not be laid upon it, because operations upon tabetic subjects, especially those exhausted and emaciated by pain and inanition, are of necessity attended with graver risks than similar procedures on other classes of patients. But the fact remains that Franke's operation has a mortality record of 15 per cent. Tabetics are said to be more susceptible to infection, and we must take this into account in estimating the risk of any operation, whether it be a Franke or a Förster. This may be true of tabetics as of any ill-nourished subject, or perhaps more particularly of subjects with spinal lesions in which the trophic supply of the operative territory may

be affected. But my own experience does not bear this out; all the wounds healed by first intention, and I am inclined to discredit the emphasis that has been laid upon infection as increasing the risk of operation.

Theoretically, the effectiveness of Franke's method depends upon the removal of the posterior root ganglia with the intercostal nerves, but in practice the accomplishment of this has not been uniformly successful. As shown in the diagrammatic reproduction of sections of the intercostal nerves actually removed, there were two out of eleven specimens in which the ganglion was left behind (Fig. 287). Thus, in some cases at least, the operation will of necessity give no relief. Sicard and Leblanc, repeating Franke's operation on the cadaver a number of times, found that in their attempts at removing the ganglia with the intercostal nerves, varying lengths of both anterior and posterior roots were carried away, and in one instance the dura was widely rent (Fig. 288). These injuries to the dura and roots must be considered when passing judgment on the Franke method. The following is his *technic:* A longitudinal incision extending from the spinous processes of the fourth to the eleventh thoracic vertebrae, six centimeters to the right of the median line, traverses the skin and subcutaneous tissue and exposes above the trapezius and below the latissimus dorsi. These muscles are divided in a line parallel to the cutaneous incision and upon the retraction of their fibers the longissimus dorsi is exposed. Care should be taken to avoid injuring the vessels which emerge between the iliocostal and longissimus dorsi muscles. With a blunt instrument the latter muscle is split longitudinally into two parts, an inner smaller and an outer larger portion. The margins of the di-

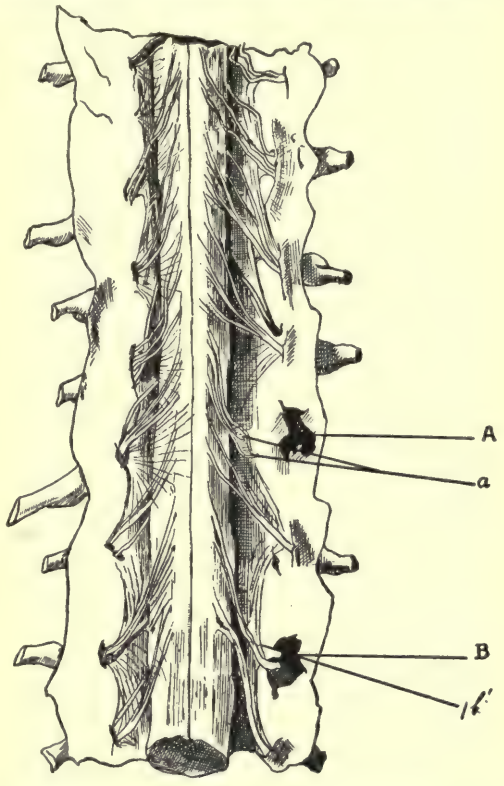


FIG. 288.—FRANKE OPERATION OF EXTRACTION OF INTERCOSTAL NERVES.

Drawing showing tears in the dura at A and B, and the points at *a* and *b* at which the anterior and posterior roots were severed in attempts at removing the spinal ganglia on the cadaver. (After Sicard and Leblanc.)

vided muscle are separated and the several attachments of the inner portion to the transverse processes are divided. The costotransverse ligament covering the vertebral extremity of the intercostal space is seized at its attachment to the transverse process and divided. Thus the intercostal space is exposed; and nothing but the external intercostal muscle, which at this line is but a membrane, and the posterior external intercostal membrane, described by Sauvé (Fig. 289), separates one from the intercostal nerves. This posterior external intercostal membrane is the important structure for the orientation of the intercostal nerves, which lie directly behind it and equidistant from the adjacent ribs. To expose the membrane the overlying tissues are separated from their attachment at the inner extremity of the intercostal space and displaced outward toward the angles of the ribs. The membrane thus exposed is divided over a groove director from without inward as far as the costotransverse ligament. Care must be taken in this maneuver to avoid injuring the pleura. The intercostal nerve, which can be seen crossing the intercostal space from above downward, is now gently detached from the underlying pleura and with a blunt instrument from the adjacent muscle and tendons up to its point of entrance into the intervertebral foramen (Fig. 290). Here the nerve is divided, the central end, seized with forceps, extracted either by the slow method of Thiersch, advocated by Franke him-

FIG. 289.—FRANKE TECHNIC FOR EXTRACTION OF INTERCOSTAL NERVES.

Exposure of the posterior external intercostal membrane beneath which lies the intercostal nerve.

self, or by the rapid method of Sauvé. The latter is said to be more effective in that it is followed more certainly by chromatolysis of the ganglionic cells.

Upon the grounds that the Franke operation of extraction of the intercostal nerves is difficult of execution, uncertain in its effects, and not devoid of risk of injury to the dura and cord, Sicard and Desmarest proposed *extradural removal of the spinal ganglia.* Their objections to extraction of the intercostal nerves are all well taken: there is the possibility of regeneration of the nerve if the ganglion be not removed. If by the use of forcible traction the ganglion be extracted with the nerve, the pleura may be injured, the dura torn, and as much or more of the anterior than the posterior root will be carried away, not without damage to the cord itself. Sicard and Desmarest have demonstrated degeneration of the cells on the anterior cornu.

The removal of the ganglia on the posterior roots is an operation not especially difficult of execution, but, as it has been practiced, it is applicable only to lesions in the thoracic region, since in the lumbosacral region the anterior roots could not be sacrificed and extradurally it would be difficult to dissociate them from the posterior roots. My opinion as to the relative merits of gangliectomy and rhizotomy is expressed on page 720. Suffice it to say here that the gangliectomy as a means of relieving gastric crises must be regarded as *sub judice,* at least until suffi-

FIG. 290.—FRANKE TECHNIC FOR EXTRACTION OF INTERCOSTAL NERVES.

Exposure of the intercostal nerve as it crosses the intercostal space. The nerve is grasped with forceps preliminary to avulsion.

cient clinical evidence, the result of operation, be forthcoming to justify its acceptance.

As practiced by its sponsors the operation is performed as follows: after the removal of the necessary number of spinous processes and laminae, a curved Deschamps needle armed with No. 0 silk is passed around the spinal nerve, including both roots and their dural sheaths, and tied at a short distance from the dura. The spinal nerve is grasped with small Kocher forceps at its point of exit through the intervertebral foramen, and the nerve cut distally and as close as possible to the ligature, practically at the inner pole of the ganglion. By gentle traction the sheath of the nerve is loosened from its periosteal attachments and by gently twisting the forceps the roots and their sheaths with the ganglia are extracted. In addition to the ganglion, which comes away intact, not only will some fibers of the mixed extrinsic nerve be included, but the rami communicantes which are given off in close proximity to the external pole of the ganglion. Desmarest practiced this operation upon a man in his forty-fourth year whose crises lasted two or three weeks at a time and recurred every two months. He had become desperate and pleaded for relief. The laminae of the fifth to the ninth thoracic vertebrae were removed, but owing to the alarming condition of the patient, attributed to the chloroform anesthesia, only three ganglia were excised, the seventh thoracic on the right and the sixth and seventh on the left side. On the right side, where two ganglia were removed, there was a zone of anesthesia for touch, pain, and temperature, but on the left with only one ganglion removed, anesthesia was not disturbed. Parenthetically, comment may be made upon the resulting anesthesia consequent upon the arrested innervation from but two roots, contrary to the postulate of Sherrington, who ascribes to each cutaneous zone representation in at least three roots. The patient was entirely relieved of the gastric crises four months after the operation, although the lightning pains in the bladder and lower extremities continued. The following year Prat employed the same operation upon a patient whose pains had recurred after the extraction of the intercostal nerves. The patient recovered and was relieved of pain.

In the list of operations for the relief of the pain of gastric crises mention has been made of Schüller's *chordotomy*. The relative merits of this as compared with other surgical measures will be discussed (*vide* p. 910) and the technic of the operation described in Chapter XVI.

Because of their objections to the Franke operation, Sauvé and Tinel have suggested, and not without reason, that equally effective and quite as permanent results could be anticipated from *ligation of the spinal nerves* at their exit from the dural sac proximal to the ganglion. Such a ligation would interrupt the reflex arc and at the same time lead to degeneration of the posterior roots. If *a priori* it can be assumed that the accompanying degeneration of the anterior root is inconsequential when

the ligation is limited to the thoracic region, the operation unquestionably entails fewer technical difficulties than any of the other extradural procedures, including ganglicctomy (Desmarest), extradural division of the posterior roots (Guleke), or extraction of the intercostal nerves (Franke). Since the operation has not been put to actual test in the human subject I will pass it by without further comment.

The operation of *subdiaphragmatic vagotomy,* whatever its merits in selected cases, is not a substitute for posterior root resection. We do not depart from the stand we have taken in this discussion from the beginning, that pain, hyperesthesia and exaggerated reflexes are of sympathetic origin and are to be relieved only by interruption at some point in the sympathetic arc. There remain the cases of excessive vomiting without pain in which Exner's proposed resection of both vagi is theoretically applicable, but I find, in looking over fourteen of Exner's cases in which peripheral vagotomy was resorted to, that pain was a conspicuous feature in all. It adds little to the force of argument for either side to select isolated cases which in one way or another do not conform to type. We must remember that under any explanation, gastric crisis is physiologically a complex phenomenon, and I see no reason either from clinical or experimental evidence to disbelieve the conclusions at which Allen has arrived, namely, that it is extremely doubtful whether the vagus plays any part in the sensory innervation of the stomach. Unquestionably it is the pain feature of gastric crises that brings the patient to the surgeon, and I suppose in over 95 per cent of all operations pain is the dominant feature. Once in a while vomiting may be so excessive or nausea so constant as to be unbearable, and in these circumstances the Exner operation would be the procedure of choice.

According to Exner's technic, the cardia is exposed through an upper abdominal incision. The peritoneal coat of the anterior surface of the stomach is incised near the diaphragm, where the two vagi are exposed by traction on the esophagus. With these manipulations at least 3 cm. of the esophageal portion is drawn below the diaphragm. Both nerves are thus exposed before they separate into branches, and one centimeter is resected from each. The wound in the peritoneal coat of the cardia is closed and the operation concluded with a gastrojejunostomy.

Altogether there are in the neighborhood of 20 vagotomies on record, 14 of these by Exner, 3 by Ranzi, 1 each by Küttner, Hildebrand, and Neumann respectively. Of the total number there were no operative deaths. Ten were recorded as successful, 3 as unsuccessful, 2 as improved, and 3 were observed but for a short time. More satisfactory information is derived from Exner's own series of 14 cases. In 7 cases which are recorded as successful, the periods of observation following operation were: 2 years and 10 months, 2 years, 22 months, 19 months, 7 months, 2½ months and 1 month. Two were reported as cured at the end of

9 months and 2 months respectively, and 2 as unimproved at the end of 19½ months and 9 months. Two patients died at the end of 1 month, but there had been improvement in the crises in both instances, and one died at the end of 21 days. One must bear in mind that in cutting the vagi, as for Exner's operation, one is not merely obliterating a terminus, but breaking a link in a very important chain. It is without doubt that pneumogastric impulses reach the celiac plexus and ganglia by way of the communicating branch or branches from the posterior aspect of the stomach, and it is inconceivable that the intestinal mechanism would be as efficient if these were cut.

I can hardly believe that the time has come to give serious consideration to Küttner's proposal of *central vagotomy near the medulla.* Again we are confronted with the physiology of gastric crises, and are told that Exner's peripheral vagotomy can be successful only when motor-vagus symptoms predominate. In all other cases of vagus crises, Küttner holds that the vagus should be resected between the jugular ganglion and the medulla in order to include the vagus sensory fibers. This procedure is not ready to be catalogued among accepted surgical procedures. If we grant, however, as Allen holds, that the vagus plays no part in the sensory innervation of the stomach, an operation which aims merely to interrupt the afferent vagal fibers could have no effect whatsoever upon the crises. The idea has been conceived, however, and applied in only one instance to only one of the two vagi. The patient, a woman in her 39th year, had extreme nausea but no pain. At a two-stage operation the left vagus was exposed at its point of exit from the medulla, the motor and sensory fibers were separated and the latter resected. The patient succumbed to a meningitis in the fifth week; in the interim the crises were less severe. Küttner and Förster believe they have demonstrated that resection of the vagus is attended with no great technical difficulties. From my experience with the surgery of the posterior fossa, and from my knowledge of the anatomical relations of the structures near the medulla, I should regard this statement as somewhat misleading.

Intradural and Extradural Rhizotomy.—In 1908, Förster conceived the idea of resecting certain posterior thoracic roots in such severe cases of gastric crises as failed to respond to other forms of treatment. At that time he acknowledged the sympathetic origin of the lesion when there was severe pain, vomiting, hyperesthesia of the skin of the epi-, meso- and hypogastrium and exaggeration of the epigastric reflex. Förster's suggestion has stood the test of time, if a period of relief covering four years be accepted in substantiation of that statement. My first experience with root section in tabetic crises was in 1911.

Severe gastric crises in a man forty years of age. Operation; laminectomy and section of the posterior roots of the seventh, eighth, ninth

and tenth thoracic segments. No recurrence when last traced one year after operation.

The patient, a man, *aet.* 40, was admitted to my service in the University Hospital Sept. 6, 1911 (File No. 10122). He complained chiefly of pain and vomiting of three years' duration. The pain was cramp-like, severe enough to double him up, and always accompanied with vomiting. There was tenderness over the hypogastrium. These attacks lasted two or three days and recurred every four to six weeks. The physical examination, excluding all negative findings, revealed the following conditions: The left pupil was larger than the right, and, while both reacted to light and distance, the reaction was sluggish. Upon the abdomen was a scar over the right rectus muscles at the site of an exploratory operation done a year before in another hospital. The knee jerks, Achilles and biceps reflexes were absent even on reënforcement. There was no ankle clonus and no Babinski. With the eyes closed the station was not good. The Wassermann reaction was, however, negative. Examination, physical and otherwise, for gastric or duodenal ulcer, gallstone disease or any upper abdomen lesion, was fruitless. A diagnosis of tabes was made, later confirmed by Dr. Charles K. Mills, and the possibility of relief by a spinal operation presented to the patient. With his approval the operation was undertaken.

Laminectomy, September 19, 1911. Under endotracheal ether anesthesia the spinous processes and laminae of the fifth, sixth and seventh thoracic vertebrae were removed. The seventh root was readily identified, coming off the cord a little above the tip of the spinous process of the fourth cervical vertebra, and in accordance with a preconceived plan the roots of the seventh, eighth, ninth and tenth thoracic segments were divided (the tenth only on one side). Following the operation there was a zone of anesthesia extending from the ninth costal cartilage to the umbilicus (Figs. 291 and 292). When the patient left the hospital two months later, he was entirely free from both pain and vomiting, and when last traced, a year later, he had no recurrence.

Considering rhizotomy for the relief of gastric crises, I am assuming that we are dealing with a reflex arc, and in the majority of instances it is the afferent limb which is affected. If this be true, rhizotomy, like other procedures which aim to interrupt the afferent limb of the arc, has a firm physiological foundation for those cases of gastric crises in which the sensory phenomena predominate. Having acknowledged that rhizotomy has a physiological basis in some types of gastric crises, the question at once comes up: How many roots, and what roots should be divided? In my first case, I divided the posterior roots of T_7, T_8, T_9 and T_{10} with absolute relief, and this was in accordance with Förster's first suggestion. Later, however, Förster included T_6, and his final postulate calls for section of at least seven roots to be selected according to the zone of greatest hyperesthesia from the fifth thoracic to the second lumbar, as representing the entire sympathetic sensory supply of the gastro-intestinal tract. To divide every root from the fifth thoracic to the second lumbar would be, of course, out of the question, so that Förster has very properly reduced the maximum number to seven. Although in my belief even this number is too large as a routine procedure, one has to be governed not

only by the results, but by the reasonableness of the procedure, and the removal of six or seven arches for the section of seven roots implies a more extensive operation than would be tolerated by the average tabetic patient.

There is no doubt that in many instances in which the improvement has been of only temporary duration, and these constitute almost 40 per cent of the listed cases, the pain returned not always in the same zone, but a little above, or, as is more often the case, a little below. In other words, what was originally a gastric crisis became an intestinal or perhaps a visceral crisis. To illustrate this point one of Guleke's cases may be cited. At the first operation only T_7, T_8, and T_9 were resected. This was followed by relief and later by recurrence. Following the resection

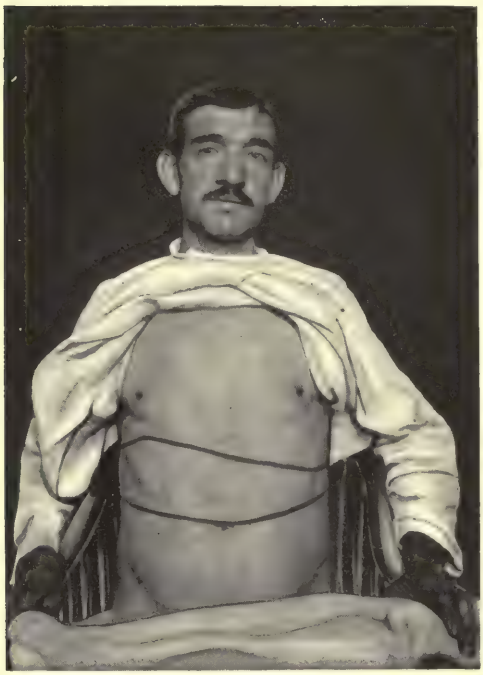


FIG. 291.—PHOTOGRAPH OF PATIENT SHOWING AREA OF ANESTHESIA FOLLOWING SECTION OF THE SEVENTH, EIGHTH, NINTH AND TENTH POSTERIOR THORACIC ROOTS FOR THE RELIEF OF GASTRIC CRISES. (Anterior view.)

FIG. 292.—PHOTOGRAPH OF PATIENT SHOWING AREA OF ANESTHESIA FOLLOWING SECTION OF THE SEVENTH, EIGHTH, NINTH AND TENTH POSTERIOR THORACIC ROOTS FOR THE RELIEF OF GASTRIC CRISES. (Posterior view.)

of T_{10} and T_{11} at a second operation the crisis disappeared. To make my position in the controversy perfectly clear, I direct the reader to the distinction between actual local recurrence and later extension of the zone of pain and hyperesthesia. At the first operation as many roots should be divided as will be represented in the zone of hyperesthesia, and this you will find in the vast majority of cases will not include more

than four or five, possibly six, roots. If, at a later period, there be recurrence of the painful crises in an area beyond the original zone of hyperesthesia, two or three more roots can be divided at a second operation. This is a sound and reasonable position; it considers the ways of reducing the risk of what must in tabetic subjects be considered a grave operation, and is founded upon an intelligent interpretation of both the immediate and ultimate results.

As a substitute for intradural section of the roots, Guleke proposed that the section be made outside the dural sac, extradural rhizotomy, on the grounds that it was a safer method. What he considers to be the dangers avoided are: infection, injury to the spinal cord, and collapse following the escape of cerebrospinal fluid. So far as one can see from the reported results there is no difference between the extradural and intradural section, nor should there be, and the selection of one or the other method resolves itself largely into a question of operative expediency. Personally, I have lost the traditional fear of the escape of cerebrospinal fluid, and disregard that as an argument either for or against an operation in this territory. Nor do I think that infection should enter into the discussion. I do concede it an open question, whether in the hands of some operators the cord might be less exposed to trauma if the manipulations were conducted extradurally. Both methods require great delicacy in every movement that by pressure or traction involves the cord.

Results.—The results of root resection for the relief of gastric crises must be submitted to a very critical analysis. The number of operations is sufficiently large to form the basis of a reliable opinion. In referring first to the immediate results, let me caution the reader against such judgment as he might hastily pass when first confronted with a relatively high mortality. The propriety of an operation must always take into account the mortality and it is with no sense of making light of this phase of the problem that attention is directed to the fact that in a large number of cases this operation has been delayed until the subject is in a state of exhaustion, often addicted to morphin, and a poor, even bad, operative risk. In the seventy-three cases in our collection, the average duration of the crises before section was six years, but in several cases they had existed for much longer periods; in one case twenty-five years had elapsed between the onset of the crises and the operation. It is, however, the habits and condition of the patient, not the duration of the crises, which seem to affect the result of the operation to any marked degree. In a case reported by Bramwell and Thomson, the patient, a man thirty-three years of age, had suffered from attacks for ten years. These often lasted as long as eighteen days, and the free intervals were never more than nine weeks. At the operation the seventh to tenth thoracic roots were divided on both sides, and there was no return of the crises during the fourteen months intervening between the opera-

tion and the report. In all of my cases the patients recovered and so far as I could see the operation itself was not attended with any alarming after-effects.

As a matter of record, in a series of seventy-three operations, which have been recorded in literature, there were ten deaths within a month of the operation, a mortality of 13.7 per cent (Table V). This is a liberal estimate, as it includes at least four cases in which death was not directly attributable to any risk peculiar to this operation. Meningitis, hematorachis, and shock might properly be charged as specific risks; of these there were five, or one-half the number of deaths; pneumonia, embolism, heart failure, cystitis and diarrhea are what might be said to be coincidental factors. The operation itself, therefore, should be charged with an operative risk of between 5 and 10 per cent.

TABLE V

CAUSE OF DEATH WITHIN ONE MONTH IN 73 CASES

Meningitis	3
Pneumonia	1
Shock	1
Pulmonary embolus	1
Cardiac paralysis	1
Cystitis	1
Diarrhea (persistent)	1
Hematorachis	1
	10 (13.7%)

Six deaths were recorded as occurring at various intervals after the first month, and of these two were due to pulmonary tuberculosis, two to pyelitis, and one to bulbar paralysis.

In addition to the above complications, which were fatal within a month, the following should be recorded:

TABLE VI

Paralysis of lower limbs	3
Temporary paralysis of lower limbs	2
Paralysis of the bladder	2
Temporary paralysis of bladder	3
" " " rectum	1
Cystitis	3
Pyelitis	2
Thrombosis of lower limb	1

Functional disturbances of the lower extremities, bladder or rectum, have been reported in a few cases and follow unquestionably too much traction or pressure upon the cord. Although observing what I considered every necessary precaution, in one of my cases there was a transitory weakness in the lower extremities and bladder. In some cases, however,

the operator reports permanent weakness of the lower limbs or of the bladder, but this was noted altogether only three times in the legs and twice in the bladder in the entire collection of 73 cases.

Briefly stated, and to give a comprehensive picture of the results of the Förster operation, I display a tabulated statement (Table VII) based upon as many cases as could be found recorded in detail in literature from 1909 to 1916. In accepting these figures the reader should do so with the understanding that the final report in some cases was made as early as four months after the operation, less frequently after one year had elapsed. Some of the cases reported as cured four or five years ago may have relapsed or the freedom from pain may have continued to this day. Furthermore, and upon this note should be taken, the list includes operations performed while the procedure was more or less in the developmental stage, as well as those performed after time and experience introduced variation in technic and in the selection of the number of roots, and that in this series of 73 operations there were 47 different operators.

TABLE VII

Results of 73 Operations for Gastric Crises

Not stated	1	(1.38 per cent)
Cured	14	(19.18 " ")
Improved	31	(42.46 " ")
Temporarily improved Later recurrence	6	(8.22 " ")
Unimproved	5	(6.85 " ")
Operative deaths (within a month)	10	(13.70 " ")
Deaths (one month or later) not due to operation	6	(8.22 " ")
	73	cases.

If this tabulated statement is acceptable as a basis of discussion, it tells us that two in ten are cured, four in ten are improved and one in ten unimproved from the beginning or with only transitory improvement.

Approximate Estimate

2 in 10 cured
4 in 10 improved
1 in 10 unimproved
1 in 10 died.

This is not a record to be considered ideal, nor is it so far from ideal as to be condemnatory of the operation or to justify an unfavorable verdict. To be able to relieve altogether or in part the pain of gastric crises by any operation in half the cases is a surgical accomplishment and a tribute to those who conceived the operation and elaborated its technic.

In the Proceedings of the Royal Society of Medicine, 1910-1911, is Förster's presentation of the subject before the Surgical Section of the British Medical Association. At that time he had collected twenty-eight cases, three of which died (11 per cent); only two showed no improvement, and in the remaining twenty-three the crises disappeared after the operation, body weight increased and the patient's general condition was very much better. Some of these even returned to work. In the eight recurrences the crises were not so severe or of so long duration. About three years later Förster again gave a summary of the operative results in 64 cases. Among the 58 who survived the operation 56 cases were recorded as successful, and only two as complete failures. Of these 56, there was no relapse in 29 cases, in 18 there was considerable improvement, and in 9 a small degree of improvement was noted.

The hopeful attitude taken by some is met with a feeling of skepticism on the part of others. Oppenheim says the results are often unsatisfactory, as there are many recurrences, and the mortality is high. Trotter and Williams express disappointment in the operation because of the number of recurrences; Cade and Leriche thought the operation could not be accepted as an established procedure until a larger percentage of permanent cures was recorded. These opinions are taken at random and many others might be quoted. There seems to be almost unanimity of opinion that the operation is rational and that unquestionably in most cases it immediately relieves the patient. Adverse criticism is founded on the short period of relief and upon recurrences. According to available data this criticism cannot be gainsaid. There are many recurrences, but, on the other hand, there are records of cases which remained free from pain beyond a time when recurrence was likely. One of Küttner's patients was free from pain after 15 months, one of von Angerer's after 18 months, one of the author's after 12 months, one of Bramwell and Thomson's for 14 months and one of Förster's for 3 years. The results have certainly been sufficiently encouraging to justify the procedure, and to establish the sympathetic origin of the crises, at least, in the majority of instances. In the series of 73 operations, both pain and vomiting were relieved in 14 cases, improved in 20, and temporarily improved with later recurrence in 6 cases. In 3 instances, the pain was cured and the vomiting improved; in 1 the pain was cured, but the vomiting returned. In 2 cases the vomiting was reported as cured, the pain improved; and in 1 case the vomiting was greatly improved, but the pain as severe as before.

If the frequency of the recurrence be the stumbling block, how is it accounted for and how may it be overcome? In the first place, recurrence must be distinguished from extension of the disease to other regions. A truly gastric crisis in the territory of T_7 to T_{10} must not be confounded with crises in the lower abdomen or the bladder. In many

instances, chiefly in the earlier period, too few roots were divided. In four instances in our collection of 73 cases it was noted that the gastric crises were improved but that intestinal crises had appeared. The selection of roots also was not always made with precise relation to the hyperesthetic zones. These are the two most patent causes of failure to relieve permanently. As an explanation of the development of pain below the epigastric region and referred to the intestines it has been suggested that the escape of blood below the seat of operation into the arachnoid membrane may be held accountable. Finally the continuation of nausea or vomiting after the operation may be charged to the irritation of the vagus. The sensory sympathetic supply of the gastro-intestinal tract includes positively T_5 to T_{12} and possibly L_1 and L_2. Although the crises originate in most cases in T_7 to T_9 it is quite reasonable to include the latter in a section. It would be quite unreasonable to include the fifth thoracic and first and second lumbar. Here lies the crux of the situation. The restricted section of T_7 to T_{10} will undoubtedly relieve in most cases, but will not prevent the development of visceral crises below the distribution of T_{10}. Hence the widest section within the bounds of reasonableness is the operation calculated not only to give immediate relief to the gastric crises, but to control possible extension of pain to wider territories.

Summary.—I have purposely dwelt at length upon the various methods of treating gastric crises. Some of them, to be sure, are but in the experimental stage, some are hypotheses, others have been tried but failed, and others have attained a measure of success. But the problem has not been solved by any manner of means, and for that reason I have gone out of my way to present a complete and comprehensive review of the various methods of treatment in the hope that, after reviewing these, some more effective method may suggest itself to a resourceful operator and student. Furthermore, this review of the relative merits of the various methods, it is hoped, will serve as a guide to the surgeon that he may avoid the hopeless and impracticable, confine his attempts at relief to the measures of reasonable promise, and perhaps evolve a more effective method than any hitherto known. Certain it is that the pain of gastric crises is severe enough to appeal to our most earnest consideration. With or without a positive Wassermann reaction every case without exception should be given vigorous antisyphilitic treatment before the question of operation should be dreamed of. In the event of failure to relieve suffering, what then? Alcoholic injections are in the developmental stage and cannot now be endorsed. Beginning with peripheral procedures, Jaboulay's operation, stretching of the solar plexus, a fanciful idea, does not deserve consideration because of inevitable recurrence. Franke's extraction of the intercostal nerves, though an extraspinal operation, has been attended with a high mortality. It is a hazardous and crude under-

taking which may carry away both anterior and posterior roots and tear the dura. Recurrence is the rule and the longest period of relief eleven months. Approaching the cord, there comes for consideration the extradural gangliectomy of Sicard and Desmarest, an operation applicable only to lesions of the thoracic region without sufficient clinical application to warrant endorsement. At this writing the records of but two cases are available, and not more than four months have elapsed since the operation was performed. Theoretically, ligation of the anterior and posterior roots, proposed by Sauvé and Tinel in 1913, appears to me as meritorious. The operation has not been tried and essentially differs in no respect from division of the posterior roots. Either intradural or extradural rhizotomy, preferably the former, is in the judgment of the writer the operation of choice. If undertaken at all, one should not wait until the patient is physically unfit as an operative subject, and at least as many roots as are represented in the area of hyperesthesia should be divided, usually five or six. If there be an extension of the crises beyond the original zone, two or three more roots may be divided at a second operation. A fair appraisal of the results of intradural rhizotomy may be expressed in these terms: two in ten cases cured, four in ten improved, one in ten unimproved and one in ten die.

The only operation to be given consideration in the vagus type of crises is Exner's subdiaphragmatic vagotomy. Exner himself tried it in fourteen cases, and of these he succeeded in relieving pain in seven. The longest period of relief at the time of the report was almost three years.

INTRADURAL ANASTOMOSIS FOR THE RELIEF OF PARALYSIS

The surgery of the spinal roots has become an accepted procedure only for the relief of such conditions as may be influenced by section and resection of the sensory roots. In 1907, Kilvington made the startling suggestion that certain paralyses might be relieved by intradural anastomosis of the anterior roots. There are but two cases on record in which the results of this operation have been reported, one of these by Kilvington and Bird in 1907, and the other by the author in 1912. Sharpe, in the fall of 1916, performed an intradural anastomosis in three children for the relief of infantile paralysis, but the report contains no statement as to the results. He anastomosed the twelfth thoracic anterior root to the fourth lumbar anterior root and the first and second lumbar anterior roots to the first and second sacral roots on one side only. The operation reported by Kilvington and Bird failed, according to Kilvington, chiefly because of certain technical errors which he felt could be avoided in the future. In my own case the patient, whether because of the operation

or as the result of spontaneous recovery of function, manifested some improvement.

Six months after a fracture of the first lumbar vertebra the patient partially recovered power in his extremities and also some sensation. Incontinence of urine persisted, however, and for its relief an intradural anastomosis of the first lumbar and third and fourth sacral roots was performed. Four years after operation improvement is noted.

The patient, *aet.* 27 (File No. 10687), was admitted to the University Hospital February 28, 1912, with the history that about seven months before he had sustained an injury to the lumbar spine by the explosion of a large gas tank.

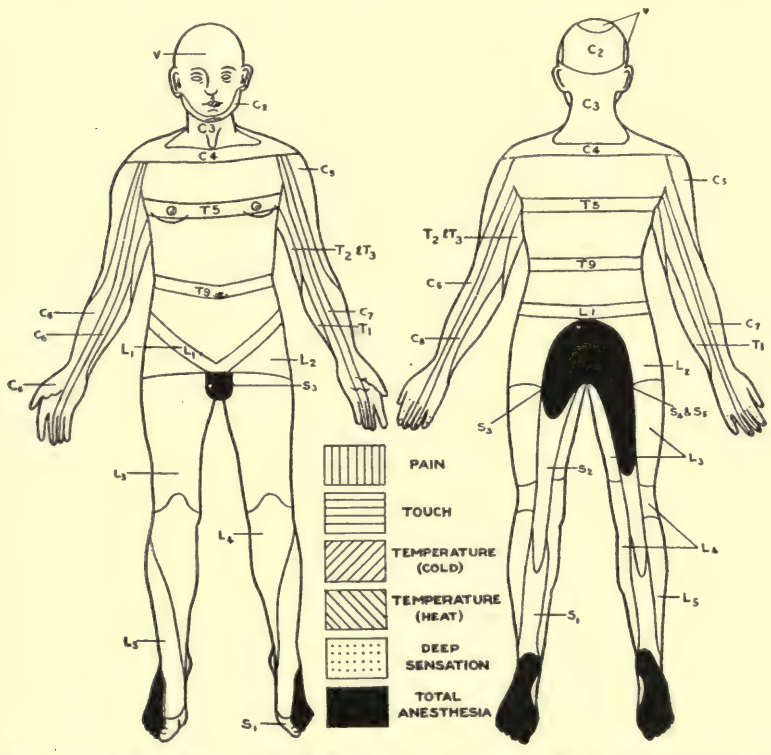


FIG. 293.—CHART SHOWING AREAS OF ANESTHESIA IN CASE OF INTRADURAL ANASTOMOSIS FOR THE RELIEF OF PARALYSIS. (University Hospital, File No. 10687.)

After the accident he was without power in both lower extremities; the bladder and rectum were paralyzed, but sensation was preserved; in fact, the skin was hyperesthetic. The patient gradually regained power in his lower extremities until, upon his admission to the hospital, he was able to walk about with the aid of a cane. At the time of his admission, a study of the areas of anesthesia indicated that the nerve-roots or segments of the cord involved were for the feet, fifth lumbar and first sacral, and for the buttock, scrotum and anal region, the second and third sacral, probably the fourth and possibly the fifth (Fig. 293). The x-ray report by

Dr. H. K. Pancoast indicated a fracture of the right half of the first lumbar vertebra. However, the patient's greatest distress and the reasons for his seeking the advice of Dr. Charles K. Mills and myself were the bladder complications. He had absolute incontinence and had to wear a urinal constantly.

After full consideration of the risks of an operation and of the uncertainty of the outcome, with the approval of the patient's brother who was a physician and at the urgent request of the patient himself, it was determined to anastomose the twelfth thoracic or first lumbar root with the third and fourth sacral roots. I performed the operation on February 29, 1912, and the following is a transcription of the notes made at that time:

Laminectomy. Intradural Anastomosis of the First Lumbar and Third and Fourth Sacral Roots. Through a curved incision a cutaneous flap was reflected and the spinous processes and laminae of the twelfth thoracic and first and second lumbar vertebrae were removed. Evidently there had been a fracture of the second lumbar vertebra, as several fragments were found quite loose and readily detached. The dural sac seemed unusually distended, and when it was opened a considerable quantity of cerebrospinal fluid escaped (from 30 to 60 c.c.), even though the patient was in the reversed Trendelenburg position with the level of the head considerably below that of the pelvis. Inspection of the cord revealed no evidence of injury. There were no adhesions, no areas of softening, in fact no abnormality that could be detected with the naked eye.

The next step in the operation was the identification of the first lumbar root. A pad electrode was applied to the shoulder on the side of the operation and a unipolar electrode applied first to the roots under examination. The twelfth thoracic and the first lumbar were stimulated within the dural sac, and the one distinguished from the other by the fact that the contractions in the case of the twelfth thoracic were confined altogether to the trunk and abdominal muscles, while in the case of the first lumbar they were associated with contractions of the extensor group of the thigh. Attention was then turned to the conus for the purpose of identifying the third sacral root. What was taken to be the second sacral was first picked up on a blunt hook, and its faradic stimulation was followed by contractions only of the big toe on the affected side. On the ground that we were dealing with the second sacral, the next two nerves adjacent to it and to the inner side were selected for the anastomosis. As it was found by measurements that the twelfth thoracic, even if divided extradurally from its point of exit from the canal, would not reach the conus, it was decided to use the first lumbar. The latter was divided extradurally at its exit from the spinal canal and brought within the dural sac through a transverse incision in the dura. An end-to-end anastomosis was effected by a single No. 1 Chinese silk suture.

After the nerves had been identified by faradization, pads saturated with a 4 per cent stovain solution were kept applied to the cord in order to block, if possible, any harmful impulses.

Toward the latter part of the operation the patient's respiration became very shallow and feeble, but on changing his position to his side and resorting to moderate stimulation, normal respiratory function was promptly restored. The dura was closed with a continuous silk suture, and the musculo-aponeurotic layer with buried catgut sutures.

The operation was necessarily long and tedious, but at no time were any special difficulties encountered, except in one instance when a vein was divided at the time the first lumbar root was cut. This was followed by quite free bleeding, readily controlled, however, by a tampon. The identification of the various roots was simpler than had been anticipated. The anastomosis was effected on the left

side only, where the sensory evidence indicated less injury to the cord or nerve roots.

On March 4, 1912, the patient complained of deep-seated pain in his thigh, making him gasp. His ankle felt stiff and sore. He thought also he could feel urine accumulating in the bladder. The description of the operation has been given without abbreviation because of its unusual character, and to emphasize the necessity of proper methods for identification of roots. The all important question, however, is as to the effect of the operation upon the bladder function. On March 27, 1912, four weeks after the operation, when the patient was discharged from the hospital, he could feel the distention of the bladder when 10 ounces of boric acid solution were introduced. Of any amount less than this, however, he was unconscious. At eight months after the operation the patient stated that he could dispense with the urinal which hitherto had been worn constantly, and that with the assistance of pressure over the suprapubic region partial evacuation of the bladder was possible.

In a more recent communication from the patient's physician dated February 24, 1916, almost four years after the operation, it is stated that the patient is now engaged as a proofreader; is able to work steadily, and has no subjective symptoms at all apart from some incontinence of urine. This, however, is not "as bad as it sounds," inasmuch as the patient is not obliged to wear a urinal, since an hour or longer may elapse without incontinence. Furthermore, urination may be instituted at any time by pressure over the pubes. The cystitis of which he complained has improved to such an extent that he is not obliged to take hexamethylenamin for weeks at a time. His physician feels encouraged inasmuch as the patient has escaped any ascending infection.

Just what influence the operation may have had upon this partial restoration of function is, of course, a matter which must be conjectural; first, because the anastomosis was carried out on but one side; second, because the improvement might have been the result of spontaneous recovery of function transmitted through the roots on the side opposite the operation.

The intradural anastomosis of the anterior roots at once opens up a field for speculation as to the possibility of regeneration, as to its application and as to its feasibility in man. On *a priori* evidence the neurilemma sheath is essential to the process of either nerve or root repair and inasmuch as the anterior root is invested with such a sheath after its emergence from the cord, regeneration is not theoretically impossible. Apart from the five operations on man there is no available material for analysis other than that derived from animal experimentation. Of this we have the experiments of Kilvington, of Cadwalader and Sweet, and of Frazier and Allen. Based upon his observations in three intradural anastomoses in dogs, Kilvington found in his operations upon dogs that when one of the lumbar roots was joined to the second and third sacral roots, electrical stimulation produced all the effects on the side of the anastomoses that it did on the side with the roots intact. Thus, in one instance when L_7 was sutured to S_2 and S_3, the site of anastomosis was exposed 176 days later, and after cutting the spinal cord at the level of the sixth lumbar segment, a faradic current applied to L_7 above the anastomosis produced: (a) vigorous contraction of the muscles of the pelvic floor; (b)

vigorous contraction of the sphincter ani, and, after ceasing the stimulation, extrusion of feces; (c) expulsion of some of the bladder contents through the urethra. As a control, L_7 on the opposite side was stimulated, but this produced no contraction of the sphincter ani, extrusion of feces, or emptying of the bladder contents. No histological studies of the specimens were made by Kilvington to confirm the clinical evidence of root regeneration, but Cadwalader and Sweet repeated Kilvington's operation in four dogs, and upon the histological examination of the specimens removed from four to thirteen months, respectively, after the operations, they found considerable connective tissue within the dura and about the nerve roots. The proximal stumps of the cut roots had developed bulbous ends similar to those observed in peripheral nerves after section, and the distal segments were degenerated and showed no evidence of new axis cylinders. There was, at the line of union, considerable accumulation of fibrous connective tissue and leukocytic infiltration separating the united ends of the nerves. This excess of scar tissue formation was believed to be the most important factor in preventing complete regeneration of nerve tissue and return of function and, in the absence of this scar tissue, regeneration might not have been arrested.

In a series of experiments performed in my laboratory by Dr. A. B. Eisenbrey, as well as in a series carried out later with Dr. Alfred Reginald Allen, the results of which were reported at the Annual Meeting of the American Neurological Association in 1913, the histological findings in the specimens removed were as follows:

Despite the greatest care in technic in the endeavor to prevent postoperative adhesions, at autopsy there was invariably found such a dense undergrowth of connective tissue at the site of operation that it was with extreme difficulty that the dissection of the involved roots could be accomplished. In fact, in a number of instances there was a solid matting together of the dura and the posterior aspect of the spinal cord, which rendered it impossible to obtain any view of the anastomosis, so that judgment of the results of the anastomosis depended altogether upon microscopical examination. They studied serial sections through the scar area. The proximal part of the nerve root in question would be followed downward to the point of anastomosis. The nearer that point was approached in the microscopical field, the more involved became the section both in fibrous tissue and in multiplication of nuclear structure. In fact, it might be said that at no point was a fiber from the superior segment found actually passing through and continuous with a fiber in the inferior segment, but, following a strand of fibers from the superior segment, that strand could be picked up in serial section below the level of scar tissue, and in a number of instances there was found in the distal segment ill-formed axis cylinders with distorted, swollen medullary sheaths in the midst of a mass of young fibrous connective tissue. In view of the time

elapsing, 5 months, between the operation and autopsy, it is almost inconceivable that there should be present at that late date any of the original axis cylinders and medullary sheaths in the distal segments. Therefore, the finding of axis cylinders and medullary sheaths, although much distorted and few in number, must be regarded in favor of the possibility of regeneration.

The application of the intradural root anastomosis should not be recom-

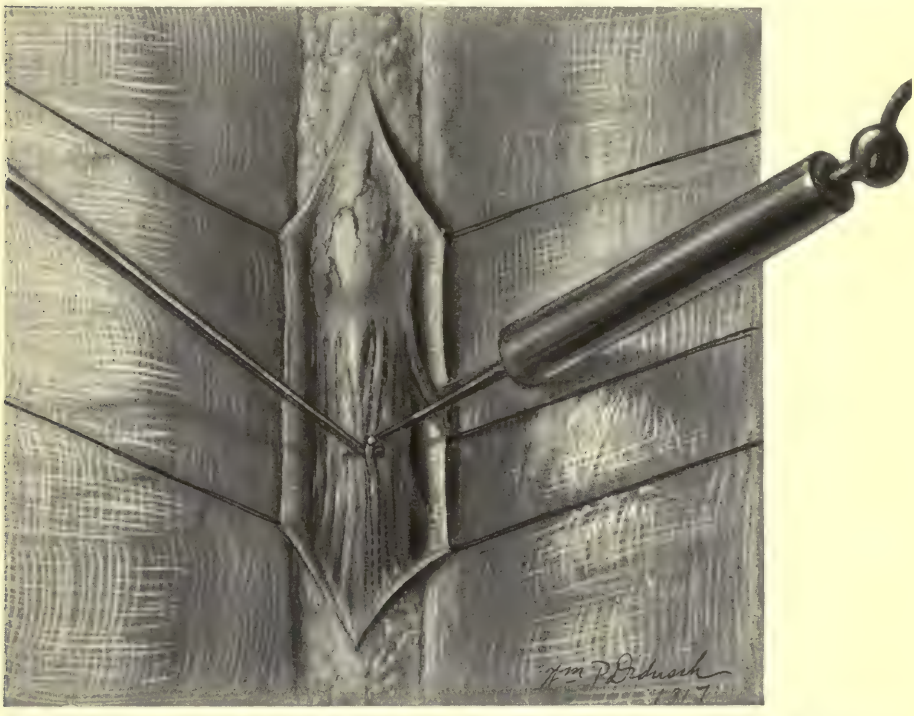


FIG. 294.—IDENTIFICATION OF THE SACRAL ROOTS BY FARADIC STIMULATION PRECEDING INTRADURAL ANASTOMOSIS.

The root is elevated on a glass hook for insulation and the unipolar electrode applied.

mended until more positive demonstrations can be made of completion of the regenerative powers by continued investigation on the lower animals. If this can be established, the operation may have a wide application, but it would be especially indicated for the relief of paralysis of the bladder musculature after injuries to the cord. The most distressing symptom is incontinence of urine and the most serious complications of traumatic lesions of the cord are the inevitable cystitis and pyelonephrosis. In fact, were it not for the latter, injuries of the spine would be robbed of their most serious complications, and the most common cause of death after recovery from the immediate consequences would be eliminated. Further-

more, one of the most common sites of fracture of the spine in the thoracico-lumbar region and of the accompanying cord injury, is just above the centers for the bladder and rectum.

The feasibility of the operation is of practical moment. According to von Frankl-Hochwart, the bladder receives its nerve supply from both the sympathetic and the somatic systems, the latter being derived from

FIG. 295.—EXPOSURE OF THE ANTERIOR DIVISION OF THE FIRST LUMBAR ROOT IN INTRADURAL ANASTOMOSIS.

A transverse slit in the dura enables the operator to expose the first lumbar root at its point of exit from the vertebral canal about a centimeter beyond where it leaves the dural sac. With a blunt hook the anterior root is separated from the posterior. The dotted lines represent the third sacral root.

the third and fourth sacral segments and roots. Assuming the injury of the cord to be at the level of the first lumbar vertebra, the segments from which comes the first lumbar root and those above would escape injury, and since the lower thoracic and the first lumbar roots do not leave the spinal canal until they pass the origin of the second and third sacral roots, it is possible to anastomose the distal ends of these roots, divided at their point of exit from the canal, to the proximal end of the third sacral root, divided at its point of emergence from the cord. As a matter of fact, it would be possible to use the eleventh or twelfth, and sometimes the tenth, thoracic root.

The performance of intradural anastomosis of the first lumbar or one of the thoracic roots immediately above to the second and third sacral roots should be carried out in accordance with the principles that are known to be essential in anastomosis of peripheral nerves. The identification of the roots is essential. The first lumbar root usually leaves the spinal canal between the first and second lumbar vertebrae. Identification of the bladder roots, the third and fourth sacral, might be difficult since the massing of the roots composing the cauda makes it hard to distinguish

FIG. 296.—INTRADURAL ANASTOMOSIS.

End-to-end anastomosis between the proximal end of the anterior division of the first lumbar root and the distal end of the third sacral root.

one from the other with any degree of certainty. But the difficulty may be overcome by applying the electrode to the sacral roots after the bladder has been filled with sterile water and a manometer attached to the catheter (Fig. 294). The expulsive effort on the part of the detrusor muscles of the bladder, elicited by stimulation of the roots with the electrode, should be recorded on the manometer. This test, easily applied, at once obviates what might be the most difficult and tedious phase of the operation. The necessary exposure is obtained by removing the spines and arches of the twelfth thoracic and the first and second lumbar vertebrae. Before the

TABLE VIII

Ventral Root Anastomoses

	Above			Below				Opposite		
Cervical	Cervical	Thoracic	Lumbar	Cervical	Thoracic	Lumbar	Sacral	Thoracic	Lumbar	Sacral
5	..	.....	.....	6*	..	....	....	.....	.....	....
6	5	.....	.....	7‡	..	....	....	.....	.....	....
7	6	.....	.....	8§	..	....	....	.....	.....	....
8	7	.....	.....	..	1†	....	....	.....	.....	....
Thoracic										
1	7*, 8	.....	.....	..	2	....	....	1*	.....	....
2	8†	1	.....	..	3	....	....	1‡, 2, 3*	.....	....
3	..	1, 2	.....	..	4	....	....	1, 2, 3, 4	.....	....
4	..	1, 2, 3	.....	..	5	....	....	1*, 2, 3, 4, 5	.....	....
5	..	2, 3, 4	.....	..	6	....	....	2, 3, 4, 5, 6*	.....	....
6	..	3, 4, 5	.....	..	7	....	....	3, 4, 5, 6, 7*	.....	....
7	..	3, 4, 5, 6	.....	..	..	....	....	4, 5, 6, 7	.....	....
8	..	5*, 6, 7	.....	..	..	....	....	6, 7, 8	.....	....
9	..	6*, 7, 8	.....	..	..	....	....	7, 8, 9	.....	....
10	..	8, 9	.....	..	..	....	....	8, 9, 10	.....	....
11	..	9*, 9, 10	.....	..	12	....	....	8, 9, 10, 11	.....	....
12	..	8‡, 9, 10, 11	.....	..	..	1	....	9, 10, 11, 12	1	....
Lumbar										
1	..	8, 9, 10, 11, 12	.....	..	..	2, 3, 4	....	10, 11, 12	1, 2, 3, 4*, 5	1, 2
2	..	11, 12	1	..	..	3, 4, 5	1, 2, 3	11, 12	1, 2, 3, 4, 5	1, 2
3	..	11, 12	1, 2	..	..	4, 5	1, 2, 3	11, 12	1, 2, 3, 4, 5	1, 2, 3
4	..	10, 11, 12	1, 2, 3	..	..	5	1, 2, 3	10, 11, 12	1, 2, 3, 4, 5	1, 2, 3
5**	..	9*, 10, 11, 12	1, 2, 3, 4	..	..	....	1, 2, 3	10, 11, 12	1, 2, 3, 4, 5	1, 2, 3

* Barely † Easily. ‡ Just. § Readily. ** 11 cm. in length.

dura is opened, the first lumbar root is divided extradurally and brought within the sac by a slit in the dura (Fig. 295). The third or fourth sacral root, identified in the manner above described, is divided on one side only as it is given off from the cord, and an end-to-end anastomosis is made between the distal end of the lumbar and the proximal end of the cut sacral roots (Fig. 296).

At the present time, I realize that we have entered a field of speculation, but the operation is so pregnant with possibilities that its omission might be criticized in a comprehensive treatise on the Surgery of the Spine and Spinal Cord. I have referred to its application to the treatment of vesical paralysis following cord lesions. The question at once suggests itself as to whether this operation might not be applicable to paralyses of other groups of muscles and we have determined from observations on the cadaver that the anastomoses which are indicated in the tabulation on the opposite page may be considered possibilities.

From this table it is readily seen that in the roots which go to make up the brachial plexus it would be possible to effect an anastomosis only between the root immediately above and the root immediately below either the fifth, sixth, seventh or eighth cervical. In the case of the first thoracic root, an anastomosis could be effected with the seventh or eighth cervical above and the first thoracic on the opposite side, and in the case of the second thoracic with the eighth cervical and first thoracic above and with the first, second and third thoracic on the opposite side. In cases of injury to the cord involving the seventh or eighth cervical segments with resulting paralyses, it would be possible to innervate the roots from these segments with the first thoracic.

The farther down the cord one goes, the longer is the distance from the point the root is given off the cord to its point of exit from the canal, and the more the roots overlap one another. When we come to the lumbosacral region, we find that the ventral roots lend themselves to innumerable possibilities of anastomosis with roots above or below and even with roots on the opposite side. It would seem quite within the range of possibility in a case of unilateral infantile palsy of the lower extremity to be able to innervate the root of the paralyzed group with a root that might be spared from the same group from the same or opposite side.

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Intradural Anastomosis for the Relief of Paralysis

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CHAPTER XI

TECHNIC OF RHIZOTOMY

For the relief of various conditions, notably pain and spasticity, rhizotomy has been awarded a place in the catalogue of accepted surgical procedures. Rhizotomy implies cutting of the rhizome or root and, as a matter of fact, more than complete division, a physical break in the continuity of the root fibers, is unnecessary. As part of the central nervous system and as conforming to the processes that prevail in all nerve tissues central to the ganglia, there can be no physiological union with recovery of function once the continuity of the root is broken. What is true of the spinal cord itself, of the sensory root of the ganglion of Gasser, is just as true of the posterior roots of the spinal cord. Hence, throughout this chapter and whenever the term is mentioned elsewhere, rhizotomy indicates nothing more than a complete division of the posterior root at some point between the spinal cord and the ganglion. One should not contemplate the execution of rhizotomy without a thorough understanding of its peculiar difficulties, without a practical, preconceived plan of root identification, without a carefully considered determination of the number of roots to be divided and without a realization of the attendant risks and dangers and familiarity with the methods of avoiding them. These and other aspects of the operation will be considered as the various steps are discussed, but by way of introduction let us decide first whether the operation shall be an intradural or extradural one, and whether a one or two-stage procedure.

The advocates of the *extradural method,* including Guleke himself, give it preference over the intradural method, chiefly on the ground that there is less risk, less danger of infection and less danger of shock from the escape of cerebrospinal fluid. As an advocate of the intradural method, I shall offset these advantages with the following disadvantages: the extradural method (Fig. 297) is not applicable to the lumbosacral region because of the difficulty of separating the dura from the vertebrae, and by the extradural method the exposure of the roots is more difficult and the possibility of damaging the cord greater because of the necessity for wider displacement of the cord to one side or the other. Infection as an element of risk in operations within the dural sac I now consider as a negligible one, at least it has been eliminated from my clinic, and in considering the *pros* and *cons* of an intradural or extradural operation, I disregard it. The same may be said of the escape of cerebrospinal fluid,

the fear of which is traditional and still looms up phantom-like in the surgeon's mind. The prolonged escape of cerebrospinal fluid is sometimes attended with serious effect, but such fluid as may escape from the dural sac during the course of the operation, if proper precautions be taken, is inconsequential. The operating table should be so inclined that the opening in the dura represents the highest level, the summit of the

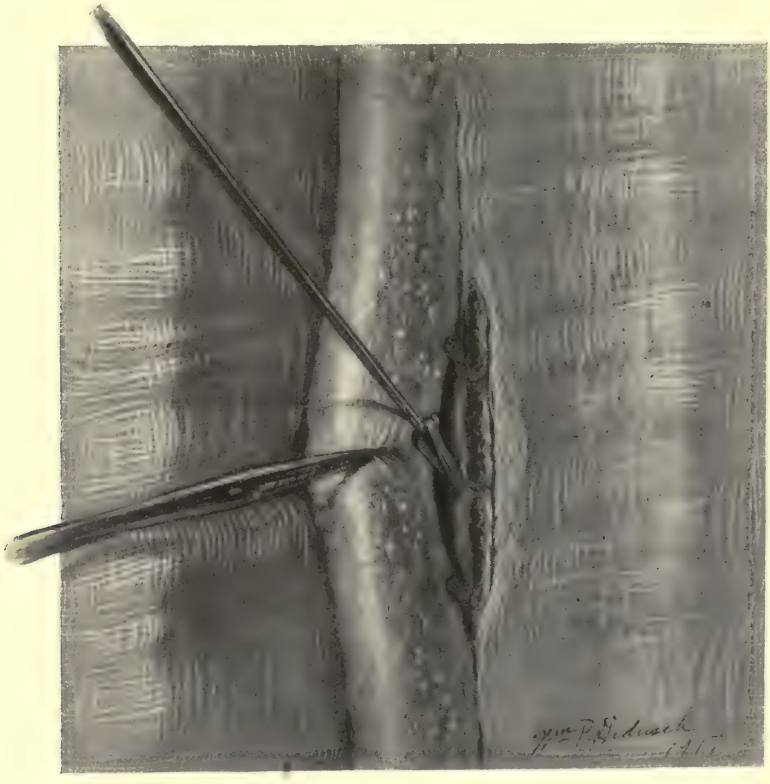

FIG. 297.—EXTRADURAL RHIZOTOMY.

The dura is grasped with mosquito forceps with which the cord is rotated and drawn to the opposite side. With a blunt hook the posterior root is separated from the anterior root. The extradural rhizotomy requires a wider exposure and the separation of the roots is more difficult because of the prolongation of the dural sheath.

subarachnoid space (*vide* Chapter on Laminectomy, page 876) and pledgets of cotton should be gently placed between cord and the dura at the upper and lower limits of the dural incision to arrest the escape of fluid from either direction. The intradural method unquestionably affords a more ample field for the identification of the roots with a minimum degree of trauma, and this I consider of fundamental importance. Physiologically, of course, the results of root section will be the same whether by the intradural or extradural method.

Whether the operation be performed in one or two stages must be left to the judgment of the operator. It would be folly to attempt to formulate rules to cover the many contingencies that might arise in the course of the operation and influence the surgeon in his judgment for or against the completion of the operation in one or two stages. Briefly stated, the two-stage operation should be regarded as one of necessity, never one of choice, in any individual case, when signs of impending shock necessitate the postponement of further intervention until a second operation. As a matter of personal experience, I always plan to do the operation in one stage in all laminectomies, whether for rhizotomy or other purposes; there is nothing to be gained by dividing the operation routinely into two stages, and such division certainly entails a greater risk of wound infection and unquestionably adds to the difficulty of the subsequent steps of the operation. From my records I find that in only two instances did I not complete the procedure at one operation. These were both cases of spasticity in children. In one, exposure of the roots was difficult because of adhesions between the spinal membranes, and the necessary trauma attending the dissection was soon made manifest in the effect upon the pulse and respiration. In the second case, a number of roots were divided at the first operation, but two weeks later it seemed desirable to divide additional ones. As standing firmly in favor of the one-stage operation, I am quite prepared to make exception when the condition of the patient demands it, and I am fully cognizant of the fact that our patients, whether the operation be for spasticity, gastric crises or pain, are often bed patients, poorly nourished, without much staying power and far from what I consider good surgical subjects. I should not pass this discussion by without reference to the divergent views entertained by those whose experience demands for them a hearing. The two-stage operation is championed chiefly by Küttner and Tietze, because in their experience shock is diminished, hemorrhage more readily controlled, affording a clear uninterrupted view of the roots; but with these notable exceptions the majority of surgeons favor the one-stage procedure.

To clear the way for an account of the operation itself a word must be said, if only to express disapproval, of the unilateral laminectomy. There should be not the slightest doubt in the mind of the operator as to the necessity for removing the entire arch. The widest possible exposure is none too wide for the delicate manipulations to follow in the identification and division of the roots and any restriction of the field as with a unilateral opening is to be condemned in the strongest possible terms, with perhaps one exception, an occasional instance when a small number of roots, two or three, are to be divided on one side only and that, too, in a reasonably accessible territory.

Intradural Rhizotomy.—For the division of a given number of roots intradurally a given number of laminae and spinous processes must be

resected, but before this preliminary step some means must be adopted of accurately identifying at least one of the spinous processes as a guide. This is absolutely essential for the subsequent identification of the roots and is readily accomplished with the aid of the roentgenogram. If, for example, it is planned to divide the sixth to the tenth thoracic roots, the skin over

FIG. 298.—IDENTIFICATION OF AN INDIVIDUAL VERTEBRA BEFORE OPERATION.
The x-ray picture is taken with a metal disk applied on the skin over the spinous process of a vertebra within the field of operation. Before the disk is removed the site is marked with silver nitrate.

what seems to be the tip of the spinous process of the eighth thoracic vertebra is marked with caustic silver. Upon this mark a strip of metal is attached, an x-ray taken, and from the plate the exact level of the silver mark can be verified (Fig. 298). If the eighth thoracic vertebra has been identified, and we know the eighth root leaves the dural sac almost without exception between the eighth and ninth thoracic vertebrae, using the eighth root as a guide there is no difficulty in identifying the sixth

and seventh as immediately above and the ninth and tenth as immediately below. The number of spinous processes and laminae to be removed will be regulated by the number of roots to be divided. (The technical steps in the removal of the laminae are described on page 885.) Before the spinous process of the eighth thoracic vertebra, or of whichever vertebra is identified, is removed and after the skin flap has been resected and the muscles separated from the spines, a silk stitch is introduced on either side through the margin of the aponeurotic layer. These sutures are to be the guide sutures and take the place of the bony landmark about to be removed.

After removal of the necessary number of laminae the dura should not be opened until every means has been employed to make the field bloodless. Bleeding points in the muscles are ligated, oozing from the cut sections of bone controlled by wax, and bleeding from the plexus of epidural veins by tampon or ligature. For various reasons the strongest precautions must be taken to prevent the escape of blood within the dural sac. The field should be and can be bloodless. As a final step before the dural incision is made, rolls of cotton as long as the wound and as thick as a pencil are laid throughout the length of the wound on either side, and over these rolls the dural flaps are reflected. These cotton rolls will absorb such blood as may escape from the surrounding structures before it can enter the dural sac, and as they become saturated they should be removed from time to time throughout the operation.

The *identification of the roots* requires an exact knowledge of their anatomical relations as to their point of origin in the cord and of exit from the dural sac. That mistakes will be made occasionally is inevitable, because of the many departures from the normal. In rare instances more than one root will make its exit through the same opening in the dural sac, as in Gottstein's case, where the fifth lumbar and first sacral left the sac through a common exit. Occasionally an entire root is lacking; in examining sixteen spinal cords, Adamkiewicz found only three in which the number of thoracic roots was complete, and very frequently the posterior root of the first cervical nerve has been found wanting. Identification is also made difficult by the intercommunications which sometimes take place between the filaments of adjoining roots. Another cause for uncertainty in identification of roots is the variations in the length of the cord and in the relation of the cord segments to individual vertebrae. In fetal life the cord occupies almost the whole vertebral canal, but as the fetus develops we find that at birth the cord extends only as far as the third lumbar vertebra. But further changes take place as the infant grows to childhood and to adult age, when the cord terminates between the first and second lumbar vertebrae. During this transitional stage the thoracic portion of the cord lengthens proportionately more rapidly than other segments. From this it will be deduced that at different ages the relationship of cord and

roots to intercostal foramina must change, as, for example, in childhood the thoracic roots have a longer course within the dural sac, and the same may be said to a less degree of the lumbosacral roots. Even in normal adults there is marked variation in the relation of the spines of the vertebrae to the cord segments. This has been emphasized by Reid and by Muskens, who found the greatest variation in the thoracic region, a difference in the intraspinal course of the roots covered by three spinous processes. In spite of these variations we must be guided in attempts at identification by the prevailing relationship, in the most constant of which C_2 is given off on a level with the arch of the atlas, T_1 with the spine of the sixth or seventh cervical vertebra, and T_7 on a level with the spines of the fourth or fifth thoracic vertebra. For practical purposes, the identification of the roots may be considered regionally, since in the vast majority of cases this operation is performed for the relief of pain or spasticity in the upper extremity, pain in the upper abdomen, or for pain or spasticity in the lower extremity. These three regions are represented respectively by (1) C_5 to T_2, (2) T_6 to T_{12} and (3) L_2 to S_2 (Table I).

TABLE I

Number of Roots to Be Cut	Landmark	Spinous Processes; Number of Laminae to Be Removed
C_5 to T_2	Tip of spinous process of the fifth cervical corresponds to point at which C_6 leaves dural sac.	Those of the fourth, fifth, sixth and seventh cervical vertebrae; possibly the first thoracic vertebra.
T_6 to T_{12}	Tip of spinous process of the sixth thoracic vertebra corresponds to the point at which T_8 leaves the dural sac.	Those of the fifth, sixth, seventh, eighth, ninth and tenth thoracic vertebrae.
Lower exposure L_2, L_3, L_5 S_1, S_2	Tip of spinous process of second lumbar vertebra corresponds to the point at which L_2 leaves dural sac.	Those of the second, third, fourth and fifth lumbar vertebrae.
High exposure L_2, L_3, L_5 S_1, S_2	Tip of spinous process of the eleventh thoracic vertebrae corresponds to the point at which L_2 leaves the cord.	Those of the eleventh, twelfth thoracic, first and second lumbar vertebrae.

(1) Orientation of the roots in the cervical and upper thoracic cord is comparatively simple. In the cervical region the upper roots are smaller than the lower, the first being the smallest. The second thoracic is very small and may thus be differentiated from the first thoracic; and

the latter is somewhat smaller than the eighth cervical. The fifth, sixth and seventh cervical are about the same size, although the sixth is usually a trifle larger than the others. At the level of the cervical cord the distance traversed by the roots within the sac from the point given off from the cord to their exit is shortest, and as one proceeds caudad the greater is the obliquity of the roots and consequently the greater their length. Thus the fifth cervical root leaves the dural sac about on a level with its point of origin. The fifth root is on a level with the fourth laminae and to expose C_5 to T_2 will necessitate the removal of the laminae of the fourth to the seventh cervical vertebrae and possibly that of the first thoracic. The separation of the anterior from the posterior roots at this level presents little difficulty, as the cord lies between them.

(2) To identify the roots of the lower thoracic cord, T_6 to T_{12}, there should not be much difficulty, although one must take into account that at this level the roots make their exit usually two, and in the lowest portion of the thoracic region three, vertebrae lower than the corresponding cord segment. Thus T_6 has its origin at the fourth thoracic vertebra and makes its exit between the sixth and seventh. The thoracic roots, with the exception of the first, are small and fairly uniform in size. The posterior roots are only slightly larger than the anterior at this level, and the fibers of both are very much spread out. As a landmark one may select the tip of the spinous process of the sixth thoracic vertebra as a guide to the point of exit of T_8. To divide roots T_6 to T_{12} inclusive would necessitate the removal of the spinous processes and laminae of the fifth to the tenth thoracic vertebrae. While the tenth thoracic root leaves the sac opposite the space between the tenth and eleventh vertebrae, both the eleventh and twelfth roots are given off from the cord at a higher level, so it is not necessary, as a rule, to remove laminae below that of the tenth thoracic.

(3) To expose the necessary number of roots in the lumbosacral cord, L_2 to S_2, and to verify them by an opening in the canal that does not exceed reasonable limits, offers many difficulties. The lower lumbar and upper sacral roots are larger than those of any other spinal nerves, while those of the lowest sacral and of the coccygeal nerve are the smallest. To differentiate between anterior and posterior roots is much more difficult here, as they are very nearly the same size. While the distinction between anterior and posterior roots should be possible at the point where they are given off from the conus, the identification of the individual roots is very difficult and almost impossible at that level. A glance at the diagrammatic sketch (Fig. 299) of the relation of the cord and its roots to the vertebral bodies shows the distance traversed by the roots within the closed sac. Thus L_2 is given off from the cord at the level of the eleventh thoracic vertebra and leaves the canal below the second lumbar. In the upper groups C_5 to T_2 and T_6 to T_{12} the roots are identified and divided at their

points of exit from the cord. To apply this plan to the division of a series of roots from L_2 to S_2 would necessitate opening the arches from the first lumbar vertebra to the second sacral. This is a matter of

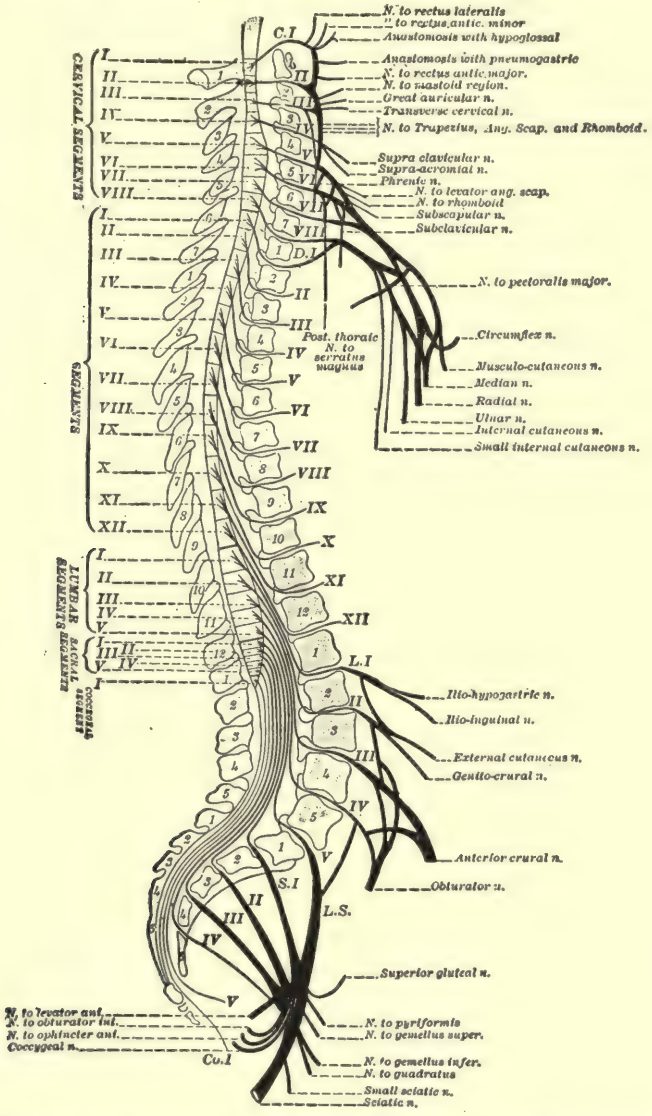

FIG. 299.—THE RELATION OF THE SEGMENTS OF THE SPINAL CORD AND THEIR NERVE-ROOTS TO THE BODIES AND SPINES ON THE VERTEBRAE. (Déjerine and Thomas.)

serious moment. The junction of the lumbar and sacral vertebrae is a point between the fixed and flexible portion of the vertebral column, a junction subjected to more or less strain, which would lose some of its

supporting strength if a number of consecutive laminae and spinous processes together with their ligamentous and muscular attachments were removed. This extensive laminectomy has, therefore, many disadvantages.

To overcome this difficulty Codivilla proposed the exposure and section of the roots while still in the conus. Such an exposure would be possible through a comparatively small opening, since the whole lumbar enlargement can be exposed by the removal of three, or at the most, four vertebral arches. We are, therefore, confronted with the problem of choosing between the high exposure of Codivilla or the lower exposure of Küttner. What are the relative merits of these two radically different procedures? As already mentioned, the high exposure necessitates the removal of but three arches, stopping at that of the second lumbar vertebra; the lower exposure, an extensive laminectomy including the arch of practically every one of the five lumbar vertebrae. In the one case the incision is higher and there is less danger of contamination; the canal is not so deep-seated and is, therefore, less difficult of access. On the other hand, the more extensive laminectomy must impair somewhat the strength of the spinal column. Up to this point because of the more limited resection, the greater accessibility of the cord, and the greater freedom from hemorrhage and shock, the higher operation would undoubtedly be chosen, granting there were no other considerations. We now come, however, to the crux of the problem, the identification of the roots. At the level of the conus, separation of the anterior from the posterior roots is not impracticable. At the lower level this separation cannot always be made with certainty, because the roots are nearly of one size and are not separated by the cord. The possibility of damaging the innervation of bladder and rectum by accidental section of the anterior roots at once emphasizes the necessity for accurate differentiation. Finally, a comparison of the two methods from the standpoint of the individual roots is unquestionably in favor of the lower exposure It is a matter of no especial difficulty, given a wide enough exposure, to identify with reasonable accuracy the roots as they make their exit from the vertebral canal. On the contrary, at the level of the conus the identification of one or a number of roots with any certainty is absolutely impossible, with the exception that the first lumbar and the third sacral may sometimes be distinguished from the others. According to Groves, the first lumbar is given off opposite the bifurcated lower extremity of the denticulate ligament and the third sacral is the lowest nerve of considerable size. Those advocating the higher conus exposure meet the objection of the difficulty of root identification with an argument somewhat as follows: provided every third nerve is spared, there results no functional disturbance of sensation or motion, complete anesthesia and ataxia accompanying only the complete division of three or more consecutive roots. Therefore, identification of each individual root is not a matter of fundamental importance, if three consecutive roots be not sectioned.

As endorsing one or the other of these methods we have a division into two camps; contending in favor of the high exposure are Codivilla, van Gehuchten, Wilms and Kolb, and Groves, and arrayed on the other side in favor of the lower exposure Förster, Tietze and Küttner. The latter represent, to be sure, only the clinic at Breslau, but their large and varied experience must bear due weight in this controversy. Were I to be the arbiter in this dispute, my decision at this time would be in favor of the Küttner-Tietze-Förster group. This opinion is based in part upon the evidence of others, but chiefly upon my own experience at the operating table and upon my study of the problem with Dr. Allen on the cadaver. My advice to the surgeon in doubt, at this writing, is to accept the disadvantages of the large and low exposure with the compensation of being able to identify and resect the desired number of roots. Should anyone doubt the wisdom of this decision he will, I think, be convinced by this first attempt in the cadaver to recognize and separate the roots without undue trauma while they are still in the conus. However, as one method may appeal to some more than others, I will outline briefly the technic of both.

The High Exposure.—Assuming the indications call for division of L_2, L_3, L_5, S_1 and S_2, the arches of the eleventh and twelfth or only the twelfth thoracic and first and second lumbar are removed. When the dura is opened, T_{12} may be identified by its point of exit from the canal between the twelfth thoracic and first lumbar vertebrae. This nerve is usually left intact. The third sacral root may be identified as the lowest root of any considerable size. Groves, who advocates this method, proceeds as follows: the filum terminale is lifted up by a fine silk ligature and a bent probe is then passed under all the posterior roots from S_3 to L_1. In this way he says all the nerves can be identified *approximately* and cut as required. van Gehuchten thinks that just as satisfactory results should be obtained by resecting only some fibers of each root. By this means the diminution of the nerve tone should be more uniform than by resecting two entire roots out of every three.

The Low Exposure.—As practiced in my clinic an incision is made to include the second to fifth lumbar vertebrae, the arches of which are removed. Usually the plan of operation includes resection of L_2, L_3 and L_5, S_1 and S_2. The first root or L_2 should leave the canal just below the second lumbar vertebra. The posterior root of the second is divided, but before dividing the third root I follow Förster's suggestion of determining beforehand which of the two supplies the extensor reflex of the knee. In most instances it is the fourth, but whether the third or fourth, that one should be spared. The exit of the first and second sacral roots is not within the region of the canal exposed, but I have been able to identify S_1 and S_2 as lying just to the inner side of L_5.

To *separate the anterior from the posterior roots* I have traced them

up as high as the exposure would allow, sometimes pinching the root lightly with forceps and noting the muscular contraction, and occasionally I have used the electrode. The separation of anterior from posterior is not so difficult in the case of L_2 and L_3 as it is lower down in S_1 and S_2. If the root be spread out as it is drawn upon a hook, the division between the anterior and posterior roots is readily seen. Occasionally, as in one of my cases, two roots may make their exit from one foramen, and this, of course, adds to the difficulty of separating the ventral from dorsal portion; and here one must trace the roots up to a level at which differentiation becomes possible.

Much space has been given to the details of root identification. Appreciating numerous departures from normal every means of identifying the roots should be in the surgeon's mind and ready for application, and before the operation is begun the number of roots to be cut should be determined. *What number and what individual roots* should be cut will depend upon the condition which the operation is designed to relieve. Thus for the relief of gastric crises as many as six or seven consecutive thoracic roots must be sacrificed; whereas in persistent postherpetic neuralgia, where the lesion is ganglionic and confined to one or two ganglia, the section of one or two roots may be all that is required. For spasticity of the lower extremity we have recommended the division of L_2, L_3, L_5, S_1 and S_2; for the relief of the pain from an inoperable tumor of the spine, the roots to be divided will be limited to those directly involved by the growth, perhaps only two or three.

Is selection of roots to be influenced by the level of the lesion? At first thought, yes; and by that I mean that the substitution of absolute loss of sensation for pain could be made with impunity in the upper abdomen, for example, but the same substitution might be a questionable practice in the arm or leg. Let us look into this matter more closely. According to the representation of Head every area large or small in the distribution of the spinal nerves, distal to the ganglia, has representation in three consecutive roots. Therefore, if any one of any three consecutive roots be cut sensation will be preserved. To spare one out of three roots has been accepted generally as a wise precautionary measure. Should this rule be observed to the letter? To answer this let us lay aside any preconceptions such as those of Head and turn to our clinical records.

We have indicated throughout this book that *"rhizotomy"* implies only cutting across (*section* or *division*), a complete break in the continuity of the root. This is true, and for the accomplishment of our purpose nothing more is necessary. Although the term *"resection"* is used synonymously with *"rhizotomy,"* it should imply the removal of a segment of the root; in fact, the recommendation has been made that a piece approximating 1 cm. should be resected. This, I believe, is physiologically unsound and practically unnecessary.

As a substitute for cutting of the root I have introduced *root-ligation,* solely as a means of securing hemostasis (Fig. 300). It is not because the bleeding obscures the field or renders the operation more difficult, but it is on the ground that uncontrolled bleeding within the cord, no matter how

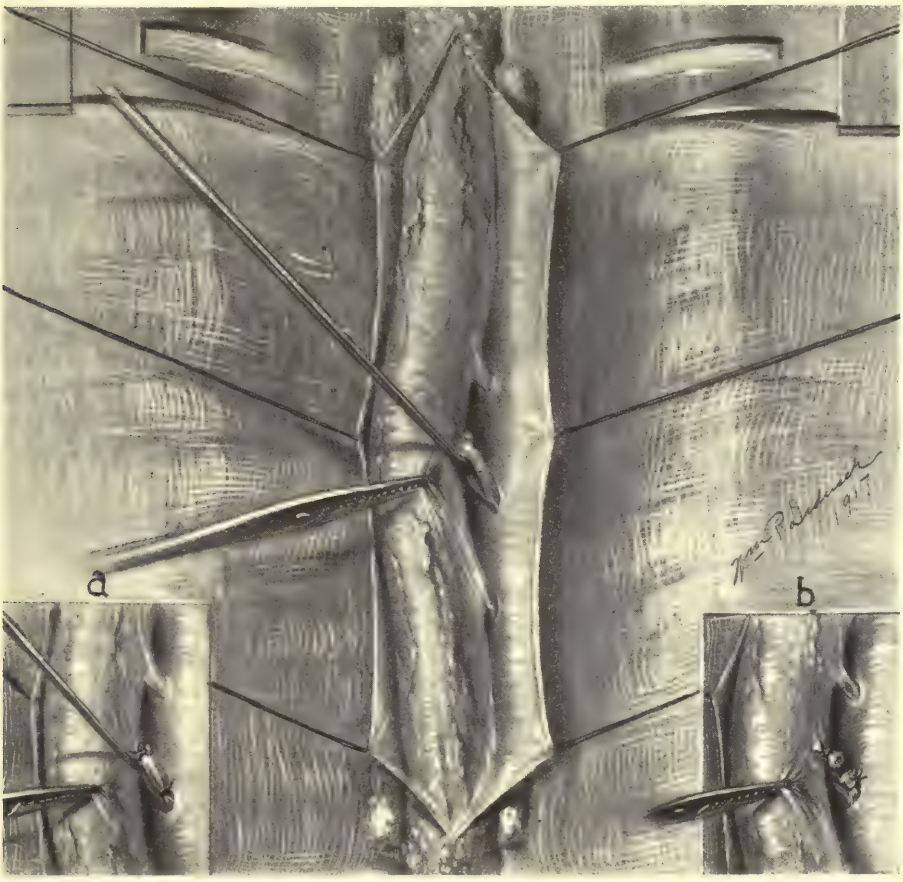

FIG. 300.—INTRADURAL RHIZOTOMY.

In the central figure the denticulate ligament is grasped with mosquito forceps, moderate traction on which rotates the cord and exposes the roots at their point of emergence from the cord and exit from the dural sac. With a small blunt hook the posterior root is separated from the anterior. *a,* A proximal and a distal ligature of fine silk have been applied prior to division. *b,* The root is divided between the proximal and distal ligatures.

trivial, is undesirable that I offer ligation as a substitute for cutting. The principal objection to the presence of blood in the dural sac is the part it plays in the development of adhesions. In the experimental laboratory, where the opportunity for the examination into the conditions following rhizotomy is readily afforded, and in rarer instances in the hospital, as in secondary operations, I have noticed that the subarachnoid space is ob-

literated. The membranes, roots and cord are, as it were, fused together, their separation being difficult if not almost impossible after sufficient time has elapsed. This fusion of structures must be through the agency of an inflammatory or traumatic exudate subsequently organizing, if not through some other agency. If asepsis be preserved, if traumatizing of the surface of the dura or pia-arachnoid in every way be scrupulously avoided, there can be no inflammatory or traumatic exudate. The agent responsible for the adhesive tissue which binds structures together is, I believe, fibrin, and this is derived from the blood that may be allowed to drain into the dural sac from the wound, a technical error, or escapes from the root vessels into the dural sac after the wound has been closed. Accompanying each of the posterior roots are an artery and a vein, and section of the root is inevitably followed by oozing, trivial perhaps, but free enough in some cases to require frequent sponging. These vessels vary in size, usually proportionate to the size of the root, and are larger, therefore, in the lumbar than cervical region; those accompanying T_{12} or L_1 are said to be the largest (Hunkin). Theoretically, these vessels should be avoided in root cutting; practically, this is impossible. Many years ago I attempted to identify them with the aid at the operation of a strong magnifying glass, but to no avail. If they cannot be avoided, hemorrhage must be controlled in some other way, and the most effective is by ligation. To be sure in some instances bleeding will stop spontaneously before the operation is ended; if not, adrenalin may be applied on pledgets of cotton with a measure of success. Unfortunately we cannot be assured that subsequent hemorrhage may not take place after the closure of the meninges.

Thus far we have spoken of the methods of identification, of separation of the anterior from the posterior root, of the number of roots to be sacrificed and the methods of resection. In the exposure of the roots and in their separation, trauma must be minimized. Too much emphasis cannot be laid upon this injunction. Call it shock, collapse, or what you will, coming on during or immediately after the operation, it is the inevitable consequence of avoidable injury to the cord or roots, and if we eliminate hemorrhage or overanesthetization as factors, the sole cause of shock or collapse at or after operation is trauma. Unfortunately, manipulation of the cord and roots with instruments is unavoidable both to bring the roots into view and to separate the anterior from the posterior portion. The cord must be retracted a little to one side or the other, but this retraction must be gentle and never enough to drag forcibly on the roots. As a constant warning on the part of myself and my assistants, I use for this purpose hooks of glass rather than of metal. With the glass hook one constantly feels the necessity of regulating and minimizing traction, knowing that under too much force the hook will break. The

hook of glass, as a non-conductor, is applicable also in identification of the anterior roots by faradization.

As a prophylactic against the harmful, if not dangerous, effect of trauma I have introduced into the technic the application of stovain to the cord and roots just above the area of manipulation, and am convinced from both experimental and clinical evidence that it has a positively beneficial influence. In a series of experiments on the lower animals I practically counteracted the harmful effects of root irritation by the use of stovain. The initial stimulation of the ventral roots with electricity was followed by a transitory rise in blood pressure, but after the application of stovain, stimulation seemed to have no effect whatsoever, as illustrated in the kymographion tracings (Fig. 301). It seems reasonable to deduce from these experiments that an effective nerve block is established by the local application of stovain. These observations of five years ago have been confirmed by Waugh, who recommends the performance of the operation under spinal anesthesia for the prevention of shock. After the dural sac is opened and the stovain-charged fluid escapes, he follows my plan of applying a pledget of cotton saturated with stovain to the highest exposed area of the cord. This serves not only to prevent shock but to maintain anesthesia.

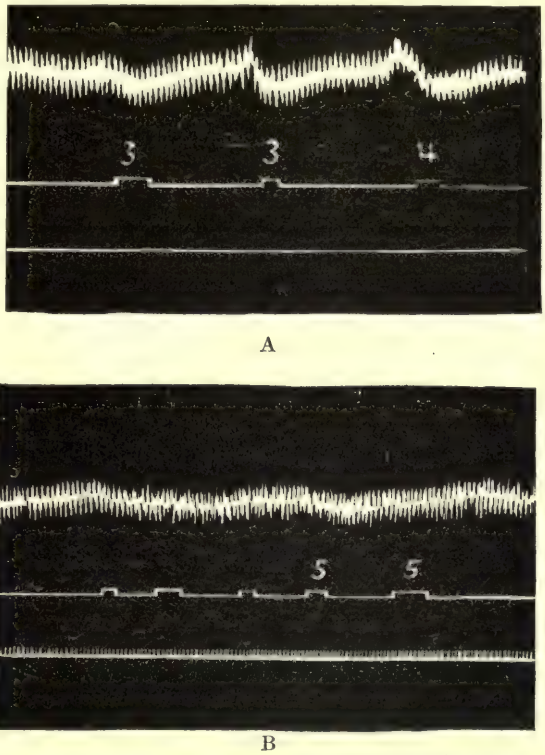

FIG. 301.—KYMOGRAPHION TRACINGS SHOWING EFFECT OF APPLICATION OF STOVAIN ON SPINAL ROOTS.

A, Showing the effect on blood pressure of electrical stimulation of the ventral roots before application of stovain. B, Showing negative results upon blood pressure of electrical stimulation of ventral roots after application of stovain.

After-Effects of Rhizotomy.—Immediately after the operation there may be signs of shock, in case preventive measures have not been heeded. Surviving any early catastrophe, the patient will complain almost immediately after the operation and for from three to five weeks of pain, at

first of considerable severity but gradually diminishing as time goes on. Pain is referred, of course, to the distribution of the roots involved and is believed to be due to the effect of the degenerative process that follows division. So that until degeneration is complete the patient may not be free from pain. Another of the after-effects I have noticed is the pain accompanying either passive or active movement of the limbs. The slightest motion soon after the operation provokes immediate protest on the part of the patient. It is rather difficult to account for this pain on motion solely on the ground that the muscles for some time prior to operation have been unaccustomed to these new movements. But as with root pains, so the pain on motion gradually disappears.

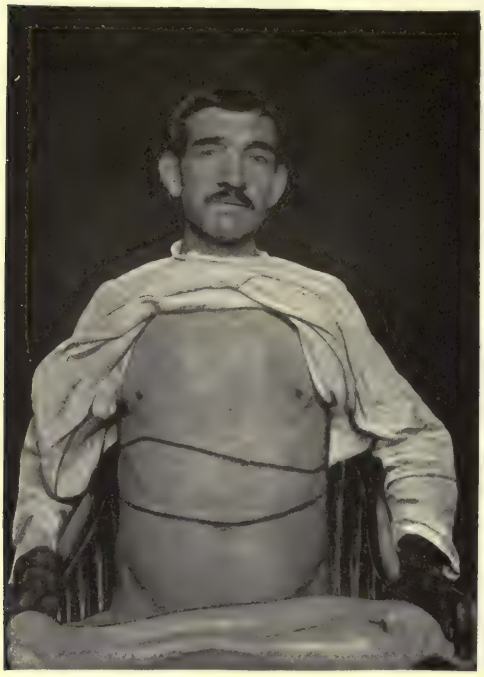

FIG. 302.—PHOTOGRAPH OF PATIENT SHOWING AREA OF ANESTHESIA FOLLOWING SECTION OF THE SEVENTH, EIGHTH, NINTH AND TENTH THORACIC ROOTS FOR THE RELIEF OF GASTRIC CRISES.

Anesthesia as a sequel of rhizotomy is more or less absolute or extensive, according to the number of roots divided. As a matter of fact, in most instances, except in operations for the relief of gastric crises, but two out of every three consecutive roots are divided. Hence, after most operations, complete anesthesia of any extent is not anticipated, but I have found isolated areas with some diminution of sensory acuity. In the thoracic and abdominal regions it is a matter of no consequence how extensive the anesthesia may be so that in gastric crises a number of consecutive roots are cut, and as a result there will be found afterwards a band of absolute anesthesia (Fig. 302). In his series of eighteen operations in fifteen patients, Hunkin found that, with the exception of a small band of anesthesia in the region of the hips in one case, there was no other evidence of permanent sensory disturbance. I have been impressed, however with the variability of the results of root section. Whether in the effect upon spasticity, upon the alleviation of pain, or in the disturbance of sensation, there is a curious variability in the effects of dividing a given number of roots in any series of cases. For example, in a case of injury to the brachial plexus in which I divided all the roots from which

the brachial plexus derives its sensory supply, pain was not altogether relieved. In some cases one finds a partial, and in others, a complete anesthesia; in some it is transitory, in others, permanent; and in others again there is hyperesthesia. These widely varying phenomena lead us into the field of speculation as to whether all afferent impulses are conducted by the posterior roots.

I have never seen any evidence of trophic disturbance following rhizotomy, nor should there be, if every third or fourth root be left intact. In Little's disease Taylor and Clark have observed some transitory trophic disturbances in the muscle and skin, but with the return of power to the limb and with a corresponding improvement in their circulation the signs of trophic disturbance disappeared. A rather interesting case was brought to my attention in reference to a spontaneous fracture attributed to the absolute analgesia that followed resection by Groves of L_4, L_5, S_1, S_2 and S_3. The patient recovered with complete anesthesia and analgesia of the limb though still complaining of excruciating pain in the leg. Four years after operation the patient reported to her physician with a fracture of both bones of the leg; of its existence or cause she had no knowledge. Subsequently Groves was able to plate the fracture without the use of any anesthetic, showing there had been no reformation of the root fibers.

The untoward effects of root section should include those incidental to accompanying injury, either to the cord itself, or to the adjacent and corresponding anterior roots. A number of instances have been reported in which there has been, following root section, complete or partial paraplegia and incontinence of urine. In most instances, however, these motor disturbances are of transitory duration or serve to emphasize the vital necessity so often referred to in this chapter of avoiding every possible source of trauma to cord and roots, either by direct pressure, by traction or by imperfect hemostasis. In one of my own series after section of the fifth, sixth and seventh thoracic sensory roots on both sides, the patient had some weakness in the right leg and retention of urine immediately after the operation, but before he was discharged from the hospital his physical power had been regained and much of the power in the leg restored.

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CHAPTER XII

LUMBAR PUNCTURE

(*Rachicentesis*)

Preliminary to the discussion of the technic of lumbar puncture it is well to call attention to certain points in the anatomy of the spine and cord in the lumbosacral region.[1] The structures to be traversed by the needle are the skin, subcutaneous tissue, ligamenta interspinalia, the ligamenta subflava, the epidural fat and plexus of veins, the dura and the arachnoid. The selection of the site is determined by two factors, the termination of the cord and the size of the interarcual spaces. In the adult the conus medullaris terminates between the first and second lumbar vertebrae, but in children, up to the first year, at the level of the third, and up to the third year, at the level of the second lumbar vertebra. Below the conus medullaris the roots of the cauda equina divide, leaving between them a space, according to Quincke, from 2 to 5 mm. wide in adults and wider in children, a space widest at the level of the second and third lumbar vertebrae (Figs. 303 and 304). Hence the needle, if introduced precisely in the median line, will not impinge upon the roots. Gerstenberg and Hein have found certain variations in the position of the roots in the subarachnoid space. Sometimes the roots are in close relation with the anterior wall, sometimes with the posterior and at other times with the lateral walls.

The interarcual spaces of the lumbar vertebrae vary somewhat in width, and while the widest are the first, third and fifth (hiatus lumbosacralis) they are all wide enough for the passage of the needle. Be it remembered, however, that sometimes there is a hook-shaped projection coming off the spinous process, which may so cover the interarcual space as to make it necessary to direct the needle obliquely upward. Though wider in children, the average dimensions of these spaces in the adult are 18 to 20 mm. in their transverse dimensions and 10 to 15 mm. in their vertical (Fig. 305).

The subarachnoid space of the lumbosacral region, the *cisterna terminalis,* has a capacity of twenty cubic centimeters and terminates at the level of the second sacral vertebra. In the spinal column the relation of the arachnoid to the dura differs from that in the cranial chamber in that

[1] For a complete description of the anatomy of the structures involved, *vide* Chapter on Anatomy of the Spine and Spinal Cord.

in the former the arachnoid is in immediate contact with the dura, while in the latter there is a fluid-containing space between the two membranes. In the region of the cisterna terminalis there is a free space between the arachnoid and the roots as a rule, although occasionally, as shown by Lusk, the roots of the cauda may be adherent to the membranes. The close rela-

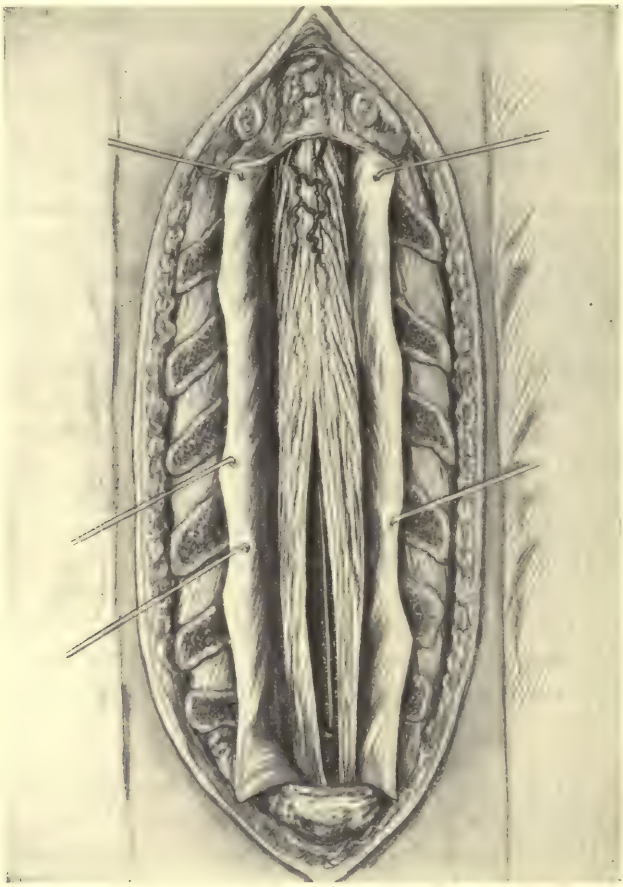

Fig. 303.—Anatomical Drawing to Represent the Space between the Bilateral Bundles of the Cauda Equina. (Compare with Fig. 304.)

tion of the arachnoid to the posterior surface of the cord from the conus medullaris to the upper cervical region is such, that attempts at lumbar puncture above the level of the conus would always be attended with the risk of penetrating the cord. Furthermore, the subarachnoid space in the region of the cauda is more open and free; higher up in the thoracic region it is divided by septa into intercommunicating spaces and in the cervical region there is a valve-like action of these partitioning membranes, which checks the free passage of fluid from the subarachnoid space of the brain

to that of the cord. This valve-like action, according to Key and Retzius, permits of the free passage of fluid from below upward, but not in the reverse direction, and Propping maintains that through the effect of the respiratory movements upon the cerebrospinal fluid this action creates a circulation of the fluid from the subarachnoid space of the cranial to that of the spinal cavity.

The distance to be traversed by the needle varies according to the age

FIG. 304.—A HORIZONTAL SECTION AT THE LEVEL OF THE FOURTH LUMBAR VERTEBRA TO ILLUSTRATE THE SPACE BETWEEN THE BILATERAL BUNDLES OF THE CAUDA EQUINA.

The lumbar puncture needle should be directed toward this space in the median line to avoid injury to the roots.

of the patient, the degree of muscular development and panniculus adiposus.

Infants and children	2-3 cm.
Frail subjects	4-6 "
Muscular subjects	6-8 "
Stout subjects	10 "

Apart from the variation in distance there is a variation in the density of the structures to be traversed by the needle. Thus in the weak and in children the ligamentous structures are much more readily penetrated than in the adult.

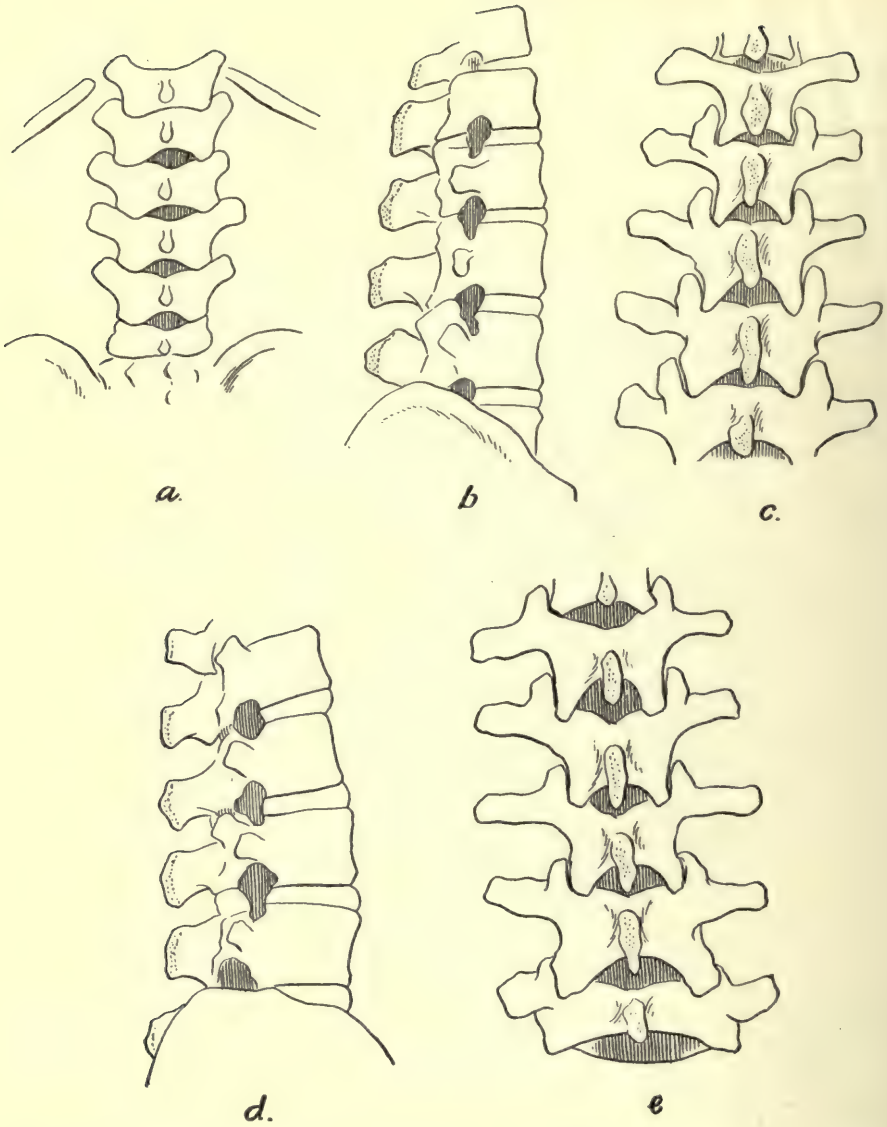

FIG. 305.—A SERIES OF ANATOMICAL DRAWINGS TO ILLUSTRATE THE FACILITY OR DIFFICULTY OF LUMBAR PUNCTURE, ACCORDING TO THE SIZE OF THE RHOMBOID SPACES AND THE SIZE AND DIRECTION OF THE SPINOUS PROCESSES. (After Quincke.)

a, The lumbar spine in a child. The spinous processes are small, the rhomboid spaces between the vertebrae wide, and there is an unobstructed approach to the dural sac.

b, The lumbar spine in an adult (lateral aspect). Note the size of the spinous processes and their horizontal direction.

c, The lumbar spine in an adult (posterior aspect). The spinous processes are large but horizontal and do not obstruct the approach to the rhomboid space.

d, The lumbar spine in an adult (lateral aspect). Note the downward direction of the spinous processes. (Compare with *e*.)

e, The lumbar spine in an adult (posterior aspect). Observe how the rhomboidal spaces are partially obstructed by the spinous processes.

TECHNIC

Selection of Site for Lumbar Puncture.—The site is determined by the size of the interarcual spaces as a matter of facility and by the anatomical relations of the cisterna terminalis to the cauda as a matter of safety. The needle must be introduced below the cord and between the bifid cauda equina at some point, therefore, from the second to the fifth lumbar vertebra. As the interspace below the third lumbar vertebra is in most

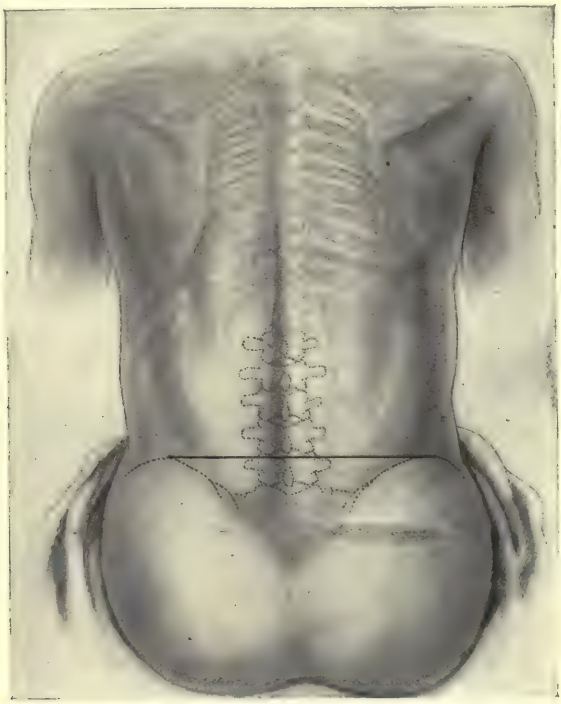

FIG. 306.—RELATIONSHIP BETWEEN A LINE DRAWN ACROSS THE ILIAC CRESTS AND THE INTERARCUAL SPACE BETWEEN THE FOURTH AND FIFTH LUMBAR VERTEBRAE, THE POINT OF ELECTION FOR LUMBAR PUNCTURE.

instances the widest and the most accessible, this is the space which Quincke indicated as the point of election. There is, however, but little difference between the third and fourth interarcual spaces, nor is it always possible in stout and muscular individuals to differentiate one from the other, although a line projected from the summit of the crests of the ilia traverses in most instances the spine of the fourth lumbar vertebra (Figs. 306 and 307). This is a most convenient guide and quite as accurate for the results as an attempt to fix this process by counting down either from the *vertebra prominens* or the twelfth thoracic vertebra. In

thin subjects and in children there is, however, little difficulty in identifying the spines. The relatively lower termination of the cord in children must be borne in mind; as the cord in infants extends as far down as the third lumbar vertebra, one should always puncture below that point. Finally, it should be an invariable rule to introduce the needle in the

FIG. 307.—THE RELATIONSHIP OF THE CRESTS OF THE ILIA AND THE SPACE BETWEEN THE FOURTH AND FIFTH LUMBAR VERTEBRAE.

median line rather than one-half to one centimeter to either side, as suggested by some. If the needle puncture the dural sac exactly in the median line, not only will injury to the roots of the cauda equina be avoided, but the operator can direct the needle with greater accuracy.

Equipment.—For the performance of lumbar puncture there are needed a pair of sterile rubber gloves, a hypodermic syringe and needle, 0.5 per cent solution novocain, a solution of 5 per cent iodin, two sterile towels, a straight Hagedorn needle, special lumbar puncture needles of various

lengths, a manometer for measuring the pressure of the cerebrospinal fluid, two sterile graduates and two sterile test tubes, a solution of collodion and an applicator (Fig. 308). All of these should be at hand for rachicentesis, and nothing more is required, unless it be some remedy or other to be used in spinal therapy. The equipment should be uniform, standardized as it were, so that the operation is carried on always under precisely the same external conditions and with instruments with which the operator is familiar. In my own clinic the lumbar puncture set includes a special needle and special manometer. The needles of various

FIG. 308.—INSTRUMENTS AND SPINAL MANOMETER FOR LUMBAR PUNCTURE, THE ESTIMATION OF SPINAL PRESSURE AND FOR INTRASPINAL THERAPY.

lengths for different ages are made of platinum with a lumen of one millimeter, and have an outlet for attachment to the manometer and one with which to withdraw fluid. A stopcock prevents the escape of fluid until the pressure is registered and the reading taken. There are many needles for spinal puncture on the market from which to choose. The one just described and depicted in Fig. 309 has what might be said to be the essential features. In the first place, it is made of platinum and not of steel. Platinum is a softer metal and easily bends when brought in contact with bone, for example, thus protecting the patient from too vigorous attempts, in inexperienced hands, to reach the canal. Secondly, the needle is of the proper caliber, neither too large nor too small. If too large, the fluid may escape too rapidly; if too small, the lumen is easily obstructed with clumps of cells or corpuscles; thirdly, and most important

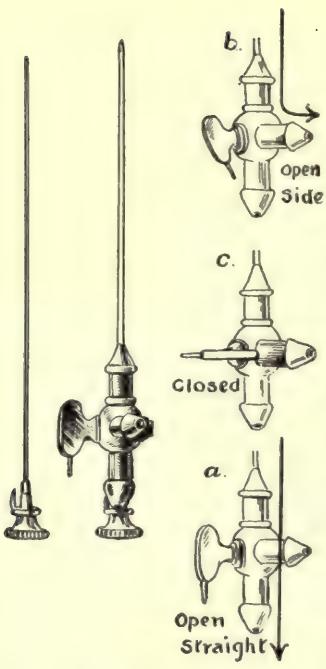

FIG. 309.—SPECIAL LUMBAR PUNCTURE NEEDLE WITH THREE-WAY STOPCOCK.

Constructed so as to allow fluid to escape, (*a*) through outlet at end of needle, (*b*) at side of needle or (*c*) to check the flow of cerebrospinal fluid when turned midway between these two points.

of all, the needle has a short, beveled tip and not a very sharp point. The advantages of this are almost self-evident; if the needle have a long beveled tip, half of the lumen may be within the dural sac and half without when the fluid first escapes, so that most or much of the fluid may spill out into the epidural space, thus leading to all sorts of inaccurate observations. (Fig. 310.) But of more moment is the greater exposure of the roots to damage with the long beveled needle. Therefore, as a matter both of accuracy and safety, the short beveled needle is the better.

As to the manometer, here again is an opportunity for selecting from a number in the service of various clinics here and abroad. The manometer adopted in my clinic registers the pressure with a mercury tube and not, as in many others, particularly the European clinics, in terms of water pressure. It is a simple, compact pocket instrument that has met every requirement for pressure observations (Fig. 311). It is a matter of regret that there has been no attempt at standardization of instruments for recording the pressure of the cerebrospinal fluid. The observations would be of much greater value were they made with a standard instrument, and it is particularly unfortunate that in some clinics the pressure is recorded in terms of water and in others in terms of mercury. While the translation of terms of mercury into terms of water pressure may be made readily, as a convenience in comparing records it would be better were the same methods of expression employed. The diversity of needles and manometers must account, in part at least, for the wide discrepancies in the records by different ob-

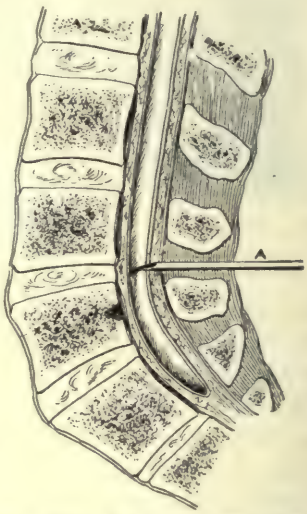

FIG. 310.—AN IMPROPERLY CONSTRUCTED NEEDLE WITH THE OPENING SO LONG AND BEVELED THAT HALF OF THE OPENING MAY BE WITHIN THE DURAL SAC AND HALF WITHOUT, ALLOWING ESCAPE OF FLUID INTO THE EPIDURAL SPACE.

servers, even of normal conditions, and these discrepancies provoke unfavorable comments as to the scientific value of the observations.

Position.—Lumbar puncture may be performed with the patient in the sitting or horizontal position. The former is permissible if the case be one

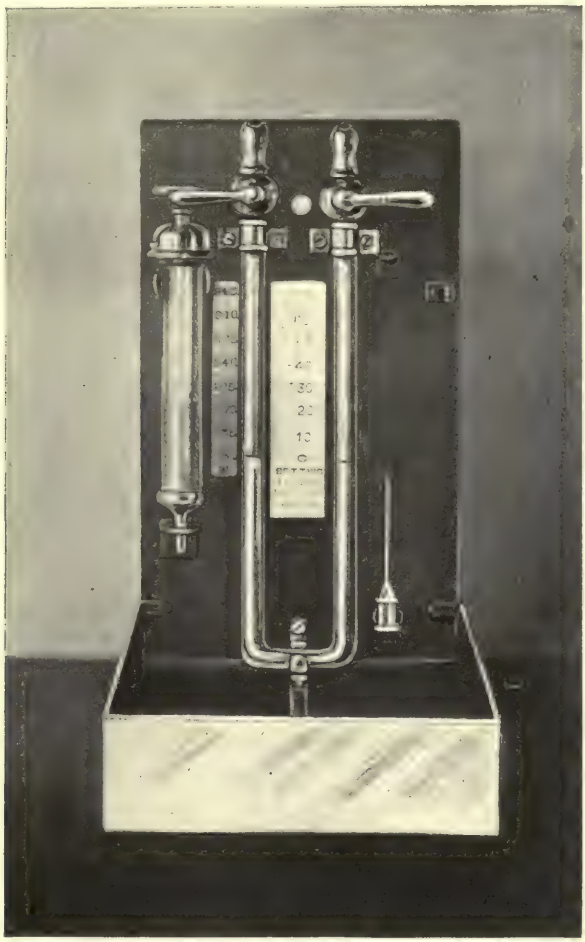

FIG. 311.—LANDON MERCURIAL MANOMETER.

The case may be closed and the stopcock turned to prevent the escape of the mercury when not in use. The scale in the center represents millimeters of mercury and the scale to the left the equivalent in water.

in which there is no reason to suspect the existence of a brain tumor, particularly of the posterior fossa. Under the latter circumstances, there should be no question as to what position should be assumed by the patient. It should be a universal practice, to which there must be no exception, to perform lumbar puncture only in the horizontal position, and chiefly for three reasons: because it is the safest; because it is less

FIG. 312.—PROPER POSITION FOR LUMBAR PUNCTURE IN RECUMBENT POSTURE. Patient brought to edge of bed or table, limbs flexed to arch the lumbar spine.

FIG. 313.—PROPER POSITION FOR LUMBAR PUNCTURE IN SITTING POSTURE.

apt to cause headache or other cephalic disturbances; and because, for the value of comparative records, observations should be made invariably in the same position. The difference in pressure between the sitting and horizontal positions is estimated at 285 mm. of water (Kroenig), varying somewhat according to whether the communication between spinal and cranial cavities be so obstructed that the circulation of the cerebrospinal

FIG. 314.—LUMBAR PUNCTURE, SITTING POSTURE.

The patient leans forward, resting elbows on thighs in order to arch the back and widen the interarcual spaces. The needle is introduced in the interspinous space below a line drawn across between the crests of the ilia.

fluid is not so free as under normal conditions. With the patient in the sitting posture the danger and the likelihood of headache are greater because of the piston-like action of the column of fluid in the spinal canal upon the brain-stem, if the fluid be withdrawn from the dependent portion of the dural sac. The weight of the column of the cerebrospinal fluid, as the latter is withdrawn, creates a negative pressure within the cranial cavity and to this negative pressure has been attributed the hyperemia and passive congestion of the brain, if not the foraminal hernia of the brain stem.

Operation.—With these remarks upon the anatomy and physiology of

the lumbar spine, the cisterna terminalis and its contents, we proceed to the description of the operation itself. The patient is placed on the edge of the bed or table, lying on the left side with the spine arched as much as possible to widen the interarcual spaces (Fig. 312), or if in the sitting posture the patient is instructed to lean forward, resting the elbows on the thighs (Fig. 313). To this end, the knees are flexed on thighs and thighs on abdomen, and to maintain this position the patient, if an adult, is instructed to clasp the hands under the bend of the knees. In children the position is maintained by an attendant. The skin is disinfected with 5 per cent tincture of iodin and the level of the fourth lumbar spine determined by stretching a sterile towel across from one crest to the other. In doing this the gloved hand of the operator should not come in contact with the skin beyond the disinfected area. The space above the spinous process of the fourth lumbar vertebra is identified by palpation and the selected point of puncture rendered anesthetic with a 0.5 per cent solution of novocain or eucain (see Fig. 318). To facilitate the passage of the round platinum needle through the skin and aponeurosis, the latter are punctured with a straight Hagedorn needle and, this laid aside, the platinum needle is grasped between the thumb and index finger and directed mesialward and slightly upward (Fig. 314). With experience the operator can visualize the passage of the needle by the relative density of the structures through which the needle passes and can thus determine when it has penetrated the interspinal ligament and ligamenta subflava. The penetration of the dura itself I have been able to recognize, and this is an invaluable sign, by the sense of the needle pricking a membrane of parch-

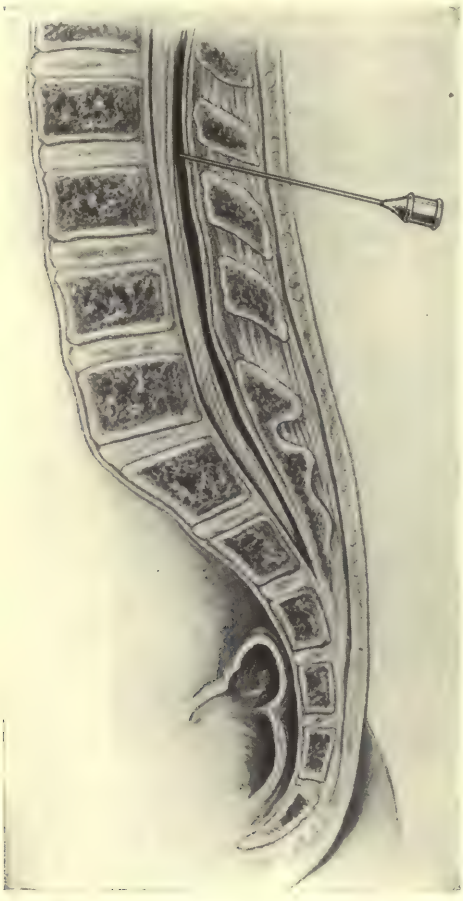

FIG. 315.—ANATOMICAL DRAWING TO ILLUSTRATE THE STRUCTURES THROUGH WHICH THE LUMBAR PUNCTURE NEEDLE PASSES: SKIN, SUBCUTANEOUS TISSUE, INTERSPINOUS LIGAMENTS, LIGAMENTA SUBFLAVA AND DURA.

ROUTINE EXAMINATION OF CEREBROSPINAL FLUID

Name	Age	Sex
Address	Admission date	Discharge date
Diagnosis	Lumbar puncture	Operation
Principal Symptoms		
Treatment	Result	

Amount of Fluid withdrawn c. c. Time Minutes

Physical Changes	(List of conditions in which fluid is to be examined routinely)
(All conditions on list)	CEREBRAL
Color	Hydrocephalus
Consistency	Meningitis
Physiological Changes	Encephalitis
Pressure at beginning	Tumors
Pressure at end	Epilepsy
Variations	Trauma
Chemical Changes	Sinus thrombosis
(All conditions on list)	Syphilitic processes
Increase in minerals	Abscess
Increase in albumin	SPINAL
Increase in sugar	Tumors
Refractive index	Trauma
Cytological Changes	Meningitis
(All conditions on list)	Syphilitic processes
Qualitative changes in cells	Myelitis
Quantitative changes in cells	Poliomyelitis
Bacteriology	Multiple sclerosis
(All kinds of meningitis)	Spastic spinal paralysis
Microörganisms	Little's disease
Serology	Spina bifida
(Hydrocephalus, serous meningitis, suspected lues)	Paresis
Wassermann reaction	Posterolateral sclerosis
Remarks	Spondylitis

ment consistency, and when this sensation is felt, and not until then, should the stylet be withdrawn (Fig. 315). If the skin be anesthetized and bony structures avoided, the procedure is practically painless; but, if by improper direction the needle come in contact with the periosteum of the bony structures, the patient will complain of more or less pain. As an act of defense he stiffens the back, straightens the lumbar spine or shifts his position, and in so doing narrows the interarcual spaces or so diverts the direction of the needle that further attempts to reach the dural sac are for the moment abandoned. It is important, therefore, that the passage of the needle should be, as it can be, painless.

The dural sac having been punctured, the stylet is withdrawn and, before more than a drop or two of fluid is allowed to escape, the reading of the cerebrospinal pressure is taken on the manometer. Subsequent to this the method of procedure varies according to the nature of the case and the purpose for which the puncture is performed, that is, whether for diagnosis or treatment. Assuming that there are no therapeutic indications for the withdrawal of fluid, how much may be and should be taken? As a matter of routine, I find that 5 c.c. will suffice for the following examinations: Wassermann reaction, cell count, cultural studies, the test for albumin and sugar. In other words, 5 c.c. is sufficient for chemical, cytological, bacteriological and serological studies, and more tests than these are not required as a routine procedure. The form on which are recorded the results of the routine examination of fluid in my clinic is on the preceding page.

FIG. 316.—MEASUREMENT OF SPINAL PRESSURE WITH MERCURIAL MANOMETER, IN THE SITTING POSTURE, BEFORE THE FLUID IS WITHDRAWN.

In this instance the cerebrospinal pressure measures 15 mm. Hg.

The rate of escape of the fluid usually varies according to the degree of pressure. Since we have come to measure the pressure with the manometer routinely (Figs. 316, 317, 319, 320 and 321), no opportunity is afforded for seeing the rate of flow, as that is checked as soon as the stylet is withdrawn. After all, the attempt to measure the pressure on the basis of drops per minute is very crude and inexact. If the first few drops be blood-tinged, the needle punctured an arachnoid vein, and this fluid must be thrown away as unfit for examination. How much fluid is to be withdrawn as a therapeutic agent will be discussed later. Suffice to say here that while withdrawing large amounts the flow should be interrupted every 1 to 5 c.c. to test the pressure, and further withdrawal of fluid after the pressure has returned to normal or reasonably near normal is not to be countenanced.

As a guide to the amount of fluid that can be safely withdrawn Kroenig has an apparatus which records not only the pressure but the wave of respiration and pulse. If the pulsations be normal, it is a sign that the communication between the dural sac and subarachnoid space of the brain is open and unobstructed; if, on the contrary, especially after coughing, the pulsations cease, communication between the arachnoid spaces of the brain and cord has been cut off and the removal of 1 c.c. might cause instant death. Kroenig interprets pronounced pulsations of the cerebrospinal fluid, if synchronous with the pulse, as suggestive either of aneurysm or of a pulsating tumor. As an additional factor of safety may be mentioned the Nonne reaction. Using his own globulinometer for the purpose, Reichmann found that by repeated estimation of the percentage of albumin, especially in cases where larger amounts are taken for therapeutic purposes, he had a very safe guide as to when he should stop. Finally the needle is withdrawn and the site of puncture sealed with liquid collodion.

FIG. 317.—MEASUREMENT OF SPINAL PRESSURE WITH MERCURIAL MANOMETER, IN THE SITTING POSTURE, BEFORE THE FLUID IS WITHDRAWN.

The stopcock has been turned and allows the cerebrospinal fluid to escape gradually. The spinal pressure drops to normal.

After-Management.—Is it safe to allow the patient to get up after a lumbar puncture? If the puncture was made only for estimation of pressure and no fluid was withdrawn, I should say *yes;* but, when fluid has been withdrawn, and especially when there is known to be increased intracranial tension from tumor or what not, the patient should be kept in bed for twenty-four hours. Not only is there then practically no risk to life, but greater freedom from headache and vomiting. Twenty-four hours in bed after lumbar puncture is a rule laid down many years ago by Quincke himself, and I am convinced of its soundness.

Fewer accidents and complications would occur if these few precautions were strictly observed: (1) Do not remove more than 5 c.c. of fluid for routine examination; (2) always evacuate slowly, interrupting

FIG. 318.—MEASUREMENT OF SPINAL PRESSURE IN RECUMBENT POSTURE.
Anesthetization of skin with novocain before the introduction of the spinal needle.

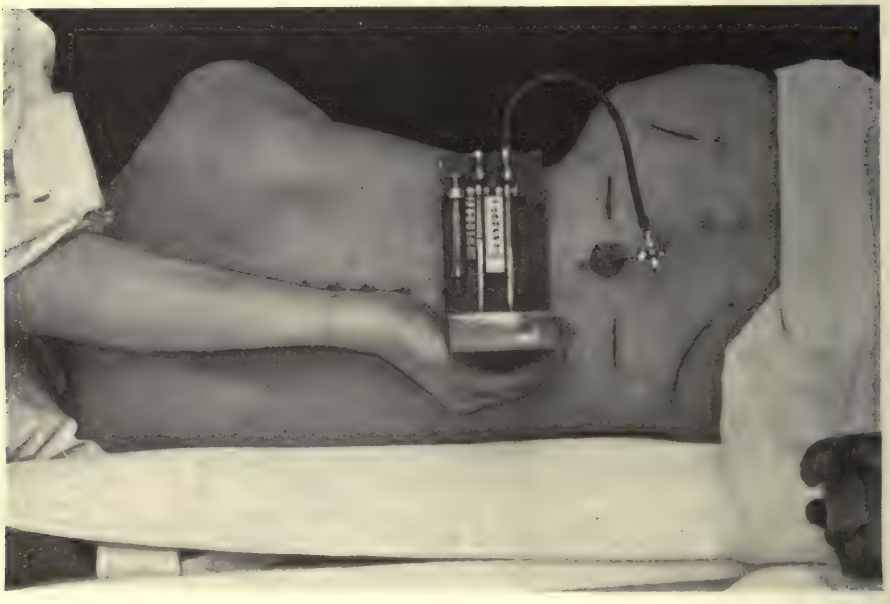

FIG. 319.—MEASUREMENT OF SPINAL PRESSURE IN RECUMBENT POSTURE.
The pressure in this case is recorded at 20 mm. Hg.

FIG. 320.—MEASUREMENT OF SPINAL PRESSURE IN RECUMBENT POSTURE.
The stopcock is open to allow the fluid to escape into the graduate.

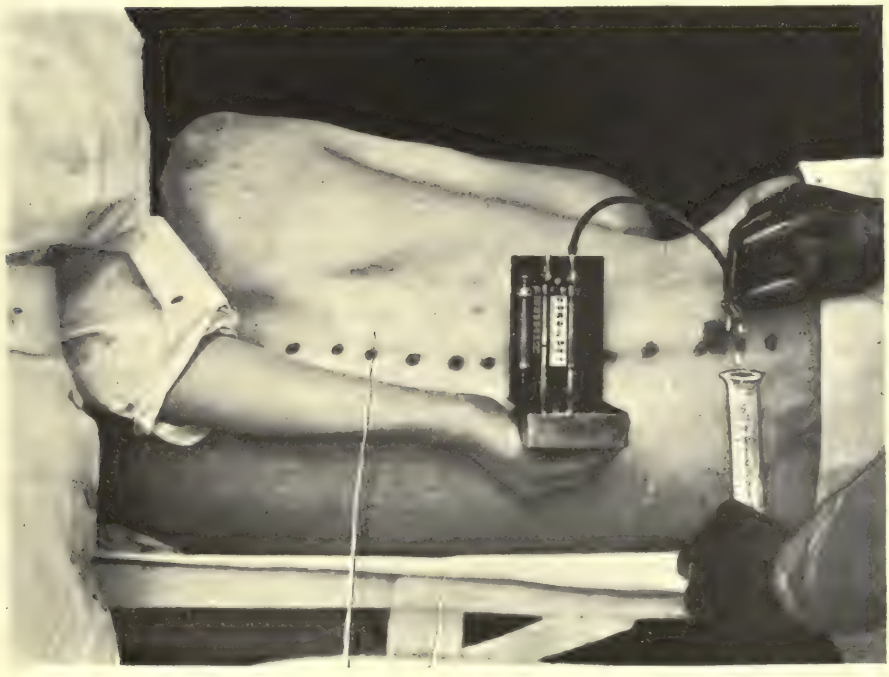

FIG. 321.—MEASUREMENT OF SPINAL PRESSURE IN RECUMBENT POSTURE.
The stopcock has been turned after 3 c.c. of fluid have been withdrawn. A second reading shows that upon the withdrawal of this amount of fluid the spinal pressure has been lowered to 15 mm. Hg.

the flow every 1 to 2 c.c. to measure the pressure; (3) the patient should always be in the horizontal position; (4) when much fluid is withdrawn and when there is increased intracranial tension, the patient should remain in bed twenty-four hours; (5) stop immediately if the patient complain of headache; (6) stop if there be a rapid fall from a high pressure record; (7) there is greater danger when the patient is sitting, and greater when the lesion within the cerebrum is chronic rather than acute.

What has been unscientifically termed a **dry tap,** is in almost every instance the fault of the operator and is not necessarily the expression of an abnormal condition in either patient or fluid. It is a technical error pure and simple in that the lumen of the needle is not within the dural sac. It may have entirely traversed the sac, it may be to one side or the other, but it is not where it should be. In exceptional cases the lumen of the needle is plugged with a piece of tissue, with a blood clot, with the purulent exudate, and in some cases no doubt by one of the roots. The fluid may be of a gelatinous consistency. If one be reasonably sure the needle has punctured the dura and no fluid follows the removal of the stylet, the latter should be reinserted and suddenly withdrawn for the suction effect, and with it will come sometimes a bit of tissue, clot or pus. I am absolutely opposed to the syringe being used for suction when the fluid does not flow spontaneously; this is a proposal not only of doubtful propriety but of grave possibilities. Very much better is it to withdraw the needle and make another attempt in an interspace above or below than it is to attempt under negative pressure to exhaust the fluid of the spinal canal. But there are cases in which, though a few drops escapé at first, the flow is soon arrested and little fluid is collected, even though the ventricles be distended. In most instances this bespeaks a recent or an old meningitis in which, through the formation of adhesions, the free passage of fluid from ventricle to spinal canal has been interrupted. That the fluid may be absent in an occasional instance was brought to my mind by an experience of Leszyorsky, who, failing to get fluid at the level of the fourth lumbar space, left the needle *in situ,* injected salt solution in the space above and saw it run out of the needle below.

Complications.—Lumbar puncture is not altogether innocuous. Whether resorted to for the purpose of diagnosis or treatment, it should be practiced only by those acquainted with the possible risks and complications and with the knowledge and the experience to safeguard the patient. The complications may be divided into two groups: (1) those which result from damage to the structures at the site of puncture, and (2) those resulting from damage to structures at a distance, that is, within the cranial cavity. Among the former may be mentioned motor and sensory disturbances in the lower extremities, pain in the back, meningitis, and among the latter, vertigo, headache, nausea, vomiting, convulsions and sudden death.

Group 1.—The least serious of the consequences is *pain in the back* at the site of puncture. Of this the patient may complain for a few hours or a few days, more or less, according to the skill of the operator. Lumbar puncture properly executed may be a painless procedure, but if the inexperienced operator succeed in reaching the dural sac only after many attempts, in which the muscles, ligaments and particularly the periosteum are jabbed with a not wisely selected needle, the patient may be excused for complaining of pain and dreads the thought of a repetition of the operation. The more serious effects of lumbar puncture are not encountered until the needle enters the dural sac. Puncture of the plexus of veins is a matter of little moment and is indicated usually by the escape of blood from the needle puncture, but after the needle enters the dural sac more or less serious consequences may result from puncture of an arachnoid vein or of one of the roots of the cauda equina. The likelihood of damage to these is minimized if the needle penetrate the sac in the median line, where there is a space 2 to 5 mm. wide between the roots of the right and the left side. Should the needle come in contact with the root, the patient complains of a sharp shooting pain down one or the other extremity. This I have observed on two occasions, but the pain is short lived and the damage only of momentary effect. Because the last sacral root occupies a position nearest the mesial line in the usual arrangement of the sacral roots, it is theoretically more frequently exposed to danger. I have never seen instances of serious sacral plexus involvement as a complication of lumbar puncture; there are, however, on record cases of paralysis not only of sphincter and bladder, but of the lower extremities as well.

Since in the cauda equina the anterior and posterior divisions of each root are in close contact, there may be both *motor and sensory effects* when the needle comes in contact with a root. Thus there may be sharp, shooting pain and muscular spasm, when the damage has been slight, or paralysis and anesthesia when the continuity of the root fibers has been impaired. In Rackemann and Taylor's patient there was a sudden, sharp contraction of the right gluteal muscle and the posterior muscles of the thigh, associated with intense pain. For three successive days he had a dull pain in the right gluteal region and walking rather aggravated the discomfort, especially if the limb were abducted. Possibly because of the position of the posterior root behind the anterior root, sensory disturbances are more often seen, although, as in the example just cited, there may be combined motor and sensory disturbances.

Aggravation of symptoms attendant upon lumbar puncture in cases of *spinal tumors* has been observed by Newmark, Nonne, Schultze and others and the reasons therefor have excited some discussion. In one instance the removal of 6 c.c. of cerebrospinal fluid from a patient with partial paralysis was followed by *total paralysis;* complete recovery fol-

lowed the removal of a psammoma from the level of the second thoracic root. In another, lumbar puncture was followed by paralysis of the four extremities with loss of sensation and reflexes, and, despite the prompt removal of a tumor from the lower cervical cord, the patient died. To be sure, there have been instances of sudden paralysis, as in von Ewald and Winckler's case, wholly independent of puncture. Serious symptoms have been known to follow lumbar puncture even though no fluid could be withdrawn, and by way of explanation Newmark suggests that arching of the spine, the position assumed during lumbar puncture, might be held responsible for the pressure phenomena, citing Schultze's case of an extradural tumor, where there was a rapid increase in the paralysis when the patient turned over on his face. Whatever the predisposing factor may be, whether posture or the withdrawal of fluid, the exciting factor must be compression of the cord, since once the pressure is relieved the symptoms entirely disappear. This was well brought out in Newmark's own clinic: immediately after an ineffectual attempt at lumbar puncture the patient complained of headache, and on the following day there was total paralysis of the left upper extremity, of both recti abdominales, with a bilateral Babinski reflex and ankle clonus. After the removal of a tumor from the level of the fourth, fifth and sixth thoracic segments there was complete restoration of function.

With the aseptic precautions that should be taken I had hardly thought it possible to precipitate a *meningitis* by a lumbar puncture. That such a disaster may occur should serve as a warning and put us on our guard against any indifference or laxity as to the observance of the essentials of an aseptic technic. The case I have in mind was recorded by van Lier, whose patient had a chondrodystrophy. Lumbar puncture, accomplished with some difficulty, was followed by a suppurative meningitis, pyemia and death.

Group 2.—Lumbar puncture should never be considered a harmless procedure, and should be practiced only with a full realization of the possible dangers, of the fact that it is more dangerous in some lesions than it is in others, and with a complete understanding of the *modus operandi* whereby the withdrawal of fluid may lead to serious consequences. Unquestionably there are three fundamental causes of cerebral disturbances, serious or otherwise—hyperemia, hemorrhage and foraminal hernia, the engagement of the brain stem in the foramen magnum. To determine the effect of the withdrawal of fluid upon the cerebral and spinal circulation, Reichmann studied the cerebrospinal fluid withdrawn by lumbar puncture immediately or a few hours after death. In six of nine cases, afterward examined at autopsy, there were changes in the brain and its membranes, associated with the appearance of blood. These changes were not always most conspicuous in the cases in which most fluid was withdrawn. In one instance after the withdrawal of 100 c.c.

the entire brain showed on section small hemorrhages, the pia was markedly injected, the inner surface of the dura was covered with free blood, and the ventricles were empty. It was observed, however, that even in the presence of similar lesions the results of the withdrawal of fluid were not always alike. In addition to these vascular disturbances, hemorrhage and hyperemia, the complications of lumbar puncture may be due, as Nissl suggests, to hypersecretion of cerebrospinal fluid and the resulting increase in intracranial pressure. From these and other observations, there is sufficient data to account at least for the more common cerebral complications, *headache, vomiting and vertigo,* and of these, by far the most common is headache. Depending upon associated conditions, such as the degree of pressure, the location of the lesion, the amount of fluid withdrawn, and the like, will the signs of meningeal irritation be more or less severe and prolonged. Usually the headache and nausea will last for a few hours, occasionally for a few days.

In only one instance have I seen any evidence of *vasomotor disturbance* after lumbar puncture. The symptoms indicated a tumor of the posterior fossa, but the tumor was not found and the brain was decompressed. Directly after a lumbar puncture, which I ventured to do for the relief of a severe headache several days after the operation, the skin of the head and neck down to the level of the clavicles became an intense dusky red. The area of discoloration was sharply defined and did not disappear for several hours. A second lumbar puncture was followed by precisely the same phenomena.

Sudden death after lumbar puncture has occurred often enough to give to this procedure a grave aspect. While the great majority of catastrophes have followed lumbar puncture upon patients with tumors of cerebrum or cerebellum, sudden death has been precipitated in other conditions as well. Thus, in a list of 38 cases Cramer gives, as the associated lesions, the following:

Cerebral tumors	16
Cerebellar "	11
" tubercle	1
Uremia	2
Tuberculous meningitis	2
Cerebrospinal "	1
Cerebellar aneurysm	2
Sylvian artery "	1
Hydatid cyst	1
Hydrocephalus	1
	38

When the patient dies immediately after lumbar puncture, and when the withdrawal of fluid is followed by an intense headache and a train

of symptoms terminating in death a few hours later, there should be no doubt. But where, for example, as in a case of tumor of the posterior fossa, the withdrawal of 3 c.c. for diagnostic purposes is accompanied by no headache and no discomfort whatsoever, yet the patient six, twelve or eighteen hours later falls a victim of medullary failure, it becomes an interesting question for debate whether the lumbar puncture was the predisposing factor, knowing as we do that sudden deaths are not so uncommon in posterior brain lesions even when there has been no lumbar puncture. In many of the cases of sudden death the clinical picture is almost uniform and gives a clew as to the immediate and responsible factors. Usually without warning, except perhaps a complaint of headache and nausea, the patient suddenly sinks into a state of unconsciousness and becomes cyanotic. An examination at once discovers respiratory embarrassment, either in the form of Cheyne-Stokes respiration, a retarded respiratory rate or more rarely complete arrest of the respiratory act. The pulse may not be affected in rate, and, provided artificial respiration is practiced in one form or another, the circulation may not be disturbed for some time. The sudden embarrassment or paralysis of the respiration could be provoked only by involvement of the respiratory center, and this unquestionably through interference with its circulation. The explanation of this phenomenon is very generally acknowledged to be the sudden pressure upon the medulla by the descent of the tonsillae cerebelli and their engagement in the foramen magnum. In 17 of the 38 cases in Cramer's collection the initial clinical picture was one of embarrassment of the respiratory center. This descent into the foramen magnum, or, as it has been called, *foraminal hernia,* is the direct consequence of the reduction of pressure in the column of fluid within the spinal canal. Assuming that the pressure of the cerebrospinal fluid at the level of the foramen magnum may be zero and the pressure in the lumbar region 10 mm. Hg or 130 mm. H_2O, the sudden withdrawal of the column of fluid from the spinal canal at the level of the fourth lumbar interspace acts, as it were, in the rôle of a piston and draws the brain stem into the foramen magnum under pressure. This so disturbs the circulation of the medulla that the function of the respiratory center is at once affected.

There is no doubt that sudden death may result from causes other than foraminal hernia. The hyperemia and the hemorrharge observed in other sections of the brain after lumbar puncture must occur as frequently in the medulla, and these lesions of themselves could be held accountable for the disturbance of the respiratory center. But death may occur wholly irrespective of medullary disturbances. For example, there have been a few cases where death has been due to *cerebral hemorrhage* from the rupture of a vessel, in some instances the seat of an aneurysm, in some instances not. The pressure of the cerebrospinal fluid in the perilymphatic spaces provides a certain amount of support to the vessel wall, and the withdrawal of

this fluid, when the vessel wall has lost its elasticity, as in arteriosclerosis, predisposes to rupture. In a case of uremia Reusch attributed sudden death following lumbar puncture to this sequence of events. From a subject with parenchymatous nephritis, suffering from severe headache and vomiting, with a blood pressure of 200 mm. Hg, 13 c.c. were withdrawn and the pressure of the cerebrospinal fluid fell from 190 to 110 mm. H_2O. The headache was somewhat relieved, but four hours after puncture the patient was found dead in bed, and at the autopsy a recent hemorrhage was discovered in the left internal capsule the size of an apple and the left ventricle was distended. Upon this hypothesis and with this experience, Reusch formulates the rule that, in uremic patients with high blood pressure, no fluid should be withdrawn if the pressure of the cerebrospinal fluid be low. In patients with high pressure of the cerebrospinal fluid and a low blood pressure, the withdrawal of fluid is attended with little danger. Another instance of respiratory death in a case of uremia was observed in a twelve-year-old boy with acute nephritis under the care of Weinländer. Forty-five minutes after lumbar puncture respiration ceased and with artificial respiration life was sustained for seventeen hours. The autopsy revealed a hemorrhage into the ventricles and pia, a chronic internal hydrocephalus and acute hemorrhagic nephritis.

APPLICATION OF LUMBAR PUNCTURE

Lumbar puncture, speaking in general terms, is indicated for one of two purposes, diagnosis or treatment, and by way of parenthesis it might be said that lumbar puncture owes its universal acceptance to its value as a diagnostic measure and in that rôle still has a much larger, though not more important, place than as a therapeutic agent. The idea of applying it to the treatment of diseases of the cerebrospinal tract was of later development.

In the chapter on The Cerebrospinal Fluid and Its Relation to Spinal Disease will be found the various departures from normal bacteriological, cytological and chemical, with their diagnostic significance, so that we will confine the discussion here to the indications and the contra-indications for lumbar puncture as a therapeutic agent. The diseases in the treatment of which lumbar puncture has been applied sometimes logically, sometimes empirically, are so varied that a classification comprehensive enough to include all would have to be a very elaborate one. If we set apart a group of miscellaneous diseases such, for example, as chorea major, spasmodic torticollis, aural vertigo, Ménière's disease, herpes zoster, chlorosis and gastric crises, and these are in the minority, there are left those in which the beneficial effect is to be attributed (1) to the relief of pressure, (2) to the withdrawal of bacterial agents or their products,

(3) to the withdrawal of the chemical products of disease, and (4) to the introduction into the subarachnoid space of certain therapeutic agents, such as the antitetanic or the antimeningococcic serum. Of all these, needless to say, it is in the relief of pressure in the subarachnoid space that lumbar puncture plays its major rôle. The isolation of specific chemical products in the cerebrospinal fluid, as a feature of this or that disease, remains for the chemist of the future, and it is a matter of speculation what influence upon the course of disease is exerted by the removal of the bacteria or their toxins, which, originating higher up in the cerebrospinal tract, find their way to the fluid in the cisterna terminalis, to be removed by lumbar puncture. The cellular elements are but the products, and not the cause, of the disease, and their removal can have but little influence over its course; neither is it easy to formulate a scientific and satisfying explanation for the beneficial effect upon the course of the disease that may come from the *removal of a number of microörganismal agents,* suspended in the cerebrospinal fluid, at some distance from the primary focus of disease. While it is a difficult matter to express, in anything like definite terms, the value of lumbar puncture as a means of removing certain pathological elements, there is no uncertainty about the part lumbar puncture plays in the relief of pressure. For these reasons it becomes very evident that, in most instances, lumbar puncture is a symptomatic, not a specific, remedy; it is designed to relieve the patient of the subjective and distressing symptoms, of the objective and threatening effects of increased pressure within the subarachnoid cavity; it is designed to tide over a critical situation while the disease is running its natural course. Such only is the explanation of its value in cases of tuberculous meningitis, of the meningitis of infectious diseases, of its effect in intracranial trauma and in uremia. But the withdrawal of fluid may have beneficial effect altogether apart from the removal of harmful products and the immediate relief which comes from *lowering pressure.* A link in the chain of the vicious circle is for the time being broken and the reaccumulation of fluid to its former state of pathological pressure is for a while delayed. Increased pressure is an important factor in the accumulation of fluid and helps to establish the vicious circle, because the greater the pressure the greater the obstruction to the natural avenues of absorption, the natural outlets of the cerebrospinal fluid. Excessive pressure causes venous stasis and inasmuch as eighty to ninety per cent of the cerebrospinal fluid is carried off by venous rather than by lymphatic channels, the effect of hypertension upon the accumulation of fluid is at once apparent.

How much fluid one can withdraw and be within the bounds of safety is a vital question, and cannot be answered by any sweeping statement. One can but lay down certain general principles. Allowing for certain conspicuous exceptions, the more acute the condition, the more fluid can

be withdrawn; in acute lesions the circulation of the central nervous system has not become adjusted to conditions of abnormal pressure, and a sudden return of pressure to normal is readily tolerated. On the other hand, the withdrawal of a large quantity of fluid, consequent upon the sudden fall of pressure, in diseases of long standing, may turn out disastrously just as paracentesis abdominalis or thoracis may, if too much fluid be withdrawn at one time.

Quite the most interesting phase of this discussion is the relation of lumbar puncture to *increased pressure* within the dural sac of the spine or the entire subarachnoid space. In the first place, if we know the pressure of the cerebrospinal fluid under normal conditions, it is an easy matter to make a pressure observation, when an increase is suspected, and upon its proper evaluation may rest the diagnosis. Unfortunately, there is still some divergence of views as to what is normal pressure; in my clinic and with the mercurial manometer, we regard 6 to 8 mm. Hg as normal pressure, with the patient in the horizontal position, and the majority of those who use water-pressure as a gauge, 100 to 130 mm. H_2O. In the second place, there is the application of lumbar puncture as a means of lowering pressure, in the treatment of certain diseases which threaten life. The gradually increasing pressure within the cranial chamber, whatever the cause, will sooner or later throttle the circulation of the vital centers in the medulla, and upon the withdrawal of fluid and the relief of pressure hangs the patient's life. Certain acute diseases, such as intracranial trauma and tumors, are examples of the conditions in which pressure may develop to an excessive degree. Thirdly, there is the relation of lumbar puncture to a group of diseases in which the increase of pressure is more moderate, but the disease is essentially chronic or at least of long duration, and lumbar puncture is practiced sometimes both to relieve discomfort and to influence the course of the disease. In this category I might cite as examples tuberculous meningitis, serous meningitis, epilepsy or the late effects of trauma.

In the treatment of **hydrocephalus,** lumbar puncture has been used both as a curative agent and as an emergency measure. Needless to say, it is of no value in that variety of hydrocephalus, hydrocephalus obstructivus, where the outlets to the lateral ventricles are obstructed, and of little value where the hydrocephalus is due to hypersecretion. There are on record a few cases (at one time I was able to collect thirteen) where repeated lumbar puncture was followed by return to approximately normal conditions. Its influence upon the clinical course of hydrocephalus must be chiefly in the relief of pressure and in its effect upon absorption. By keeping the pressure within reasonable bounds, at least one obstacle to the growth and development of the brain is removed, and by lessening the pressure upon the venous channels and subarachnoid spaces, the channels of absorption are enabled to resume their function.

I have seen diminution in the size of the head and improvement of mentality after repeated punctures, and similar observations have been made by others.

When, as a result of a preëxisting meningitis, either serous or purulent, or after an hereditary syphilitic meningitis, there is an excessive accumulation of cerebrospinal fluid, lumbar puncture frequently repeated may act as a prophylactic, and prevent the development of a hydrocephalus. Lumbar puncture has been resorted to in hydrocephalus associated with spina bifida, but with this combination the prognosis is so grave that the likelihood of being able to give more than transitory relief is remote.

An examination of the fluid in **serous meningitis** finds it under increased pressure, it may or may not reduce Fehling's solution, and there may or may not be an increase in the lymphocytes or polynuclear leukocytes; it may contain an abnormal amount of albumin, but the fluid is always clear and sterile. Because of the absence of organisms the precise nature of the infection is never disclosed, and can only be surmised in certain cases by a foregoing history of middle ear disease or some other source of infection. Whatever the source, the treatment by lumbar puncture in the acute and subacute stages is as clearly indicated as it is beneficial. In the acute cases, sometimes a single puncture suffices, but it may have to be repeated a number of times. In the chronic form, lumbar puncture may be replaced to advantage by callosal puncture or subtemporal decompression. Some light may be thrown upon the prognosis by testing for albumin. If the albumin be below 0.5 per thousand, the prognosis, according to Quincke, is favorable. A high pressure is indicative of a continued hypersecretion, and if large quantities of fluid be present, the ventricles and subarachnoid space must have expanded to the detriment, in children, of the development of the brain. Lumbar puncture will be more effective in the early than in the fully acquired forms of hydrocephalus, and, from the improvement that follows in some instances, it is reasonable to suppose that the development of the brain had been retarded by the continued pressure.

There are certain cases of serous meningitis, at least so diagnosed, because of the excess of fluid and increased pressure, but of unknown origin, where lumbar puncture may be used not only as an aid to diagnosis, but to relieve headaches. In this connection, I might refer to the relief from lumbar puncture in the severe attacks of chlorosis, in eclampsia, in the serious paroxysms of whooping-cough, in grave forms of chorea, in encephalopathia saturnina and in the headaches and threatened convulsions of uremia.

In the treatment of **epidemic cerebrospinal meningitis** lumbar puncture combined with the use of the antimeningococcic serum is unquestionably the sheet anchor. When, as in this variety, we have a specific serum

to combat the infection, the conditions for the use of lumbar puncture are ideal. As the disease is essentially acute, the puncture must be frequently repeated, often daily, and relatively large quantities of fluid, from 25 to 50 c.c., may be withdrawn (*vide* chapter on Intraspinal Therapy, p. 796). One should not wait for the development of threatening symptoms, cyanosis, respiratory embarrassment and the like. The fact that the antimeningococcic serum (Flexner) should be given daily, is an indication in itself for puncture, apart from the desirability of withdrawing toxins or perhaps relieving a degree of pressure that might in itself threaten life. By the combined use of puncture and serum, the mortality has been reduced from 70 to 25 per cent. Nothing is to be gained by the intradural injection of antibacterial solution, such as lysol, collargol, bichlorid of mercury, nor by the more radical methods of relieving pressure by cerebral decompression, or drainage of the basal cisternae through the atlanto-occipital ligament.

Lumbar puncture plays the major rôle in the management of **meningitis as a complication of infectious diseases** (influenza, typhoid fever and the exanthemata), necessarily because the only possible way of favorably influencing the course of the disease, save in the influenzal when the specific serum should be used (*vide* chapter on Intraspinal Therapy, p. 803), nay, even of saving life, is by the withdrawal of fluid. In a great many instances, however, one finds the fluid clear, even sterile, or, if the microorganisms be present, they may not be abundant, so it would appear that lumbar puncture indirectly rather than directly influences the course of the disease by relieving pressure, opening the channels of absorption, diluting the toxins, overcoming venous stasis and congestion, in this way perhaps removing factors which encourage bacterial growth. Just as obstruction to natural channels of drainage is a very potent factor in the determination and course of an infection in other organs or cavities, such as the appendix or gallbladder, the articular or pleural cavity, so in the relief of obstruction and in the restoration of the natural avenues of drainage (absorption) for the cerebrospinal fluid, we have the most potent influence of lumbar puncture. As with other forms of meningitis, the tendency to residual hydrocephalus must not be forgotten.

A very instructive example of the advantage of lumbar puncture in the tendency to hydrocephalus following meningitis is contained in a case of Connal's in which the patient was admitted to the hospital on the twenty-first day of the illness, with all the signs of cerebrospinal fever.

The fluid was turbid, the polymorphonuclear percentage was 90, the albumin measured two grams per liter, and the organisms were abundant and mainly intracellular. By the fifty-fourth day of illness the physical condition of the child pointed to the presence of hydrocephalus. Macewen's tympanitic note on percussion of the skull was present, there was prominent bulging of the anterior fontanel, and the eyes were staring. The pus cells in the fluid were 18 per cent,

the albumin was estimated at 3½ grams per liter, the intracranial tension was greatly increased, and the fluid itself was slightly opalescent. At this time daily lumbar puncture was instituted, and amounts varying between 30 and 60 c.c. of fluid were withdrawn. After two days slight turbidity of the fluid reappeared, the albumin measured 4½ grams per liter, and the intracranial tension remained high. On the fifty-ninth day of illness the fluid was almost clear again, but although no organisms were seen in the stained film, the culture was positive. Next day the culture was negative and it remained so. From this time (sixtieth day) onward, a steady improvement was observed, and when the daily lumbar punctures were discontinued, on the eightieth day of illness, the fluid, although still under considerable pressure, was clear, the albumin measured one gram per liter, and the cells were entirely mononuclear. On the 116th day there was no coagulum, and the albumin amounted to only half a gram per liter. The staring look had gone and the anterior fontanel was normal. The circumference of the head was measured from time to time. When the daily punctures were begun the measurement was 17½ inches. A fortnight later it was 17 inches, and when the punctures were stopped the measurement was 16½ inches. The child was dismissed well, and a year later she appeared to be normally bright and had learned to speak.

Finkelnburg and others look upon lumbar puncture as a useful auxiliary measure in the control of an increasing pressure, chiefly in the first stage, of **acute anterior poliomyelitis.** In this connection, I refer to the warning of Oppenheim, who called attention to the possibility of causing rupture of the vessels at the site of the lesion by lowering the intraspinal pressure.

By **purulent meningitis** we imply an infection with the pyogenic organisms, and exclude the meningitis of the infectious fevers or the exanthemata. Usually, therefore, the offending organism is the Micrococcus aureus or the streptococcus. In this variety, the source of infection may be a septic focus not communicating with the meninges (hematogenous), but more often the infection is direct, as from sinus disease, scalp wounds, fracture of vault or base of the skull, erysipelas or foci of infection in the orbit or the face. In purulent meningitis, the cerebrospinal fluid withdrawn by lumbar puncture is almost always turbid, exceptions being made for those cases in which the communication between the subarachnoid space of brain and cord has been shut off. While as a matter of routine, recourse is had to lumbar puncture, as an aid to diagnosis, to determine the nature of the infecting organism or to differentiate between a meningitis and brain abscess, the fatal tendencies of a purulent meningitis are rarely influenced by lumbar puncture, partly because of the virulence of the infecting organisms, partly because of the purulent character of the exudate, but in large measure because of the widespread adhesions. The latter conditions abound throughout the subarachnoid space of the brain, especially of the cortex, and pretty effectively shut off communication with the subarachnoid space of the spinal cord, so that at least a considerable territory in the subarachnoid

space is not reached by lumbar puncture, the toxins and microörganisms being practically inaccessible. Probably to these several factors, therefore, is to be attributed the almost hopeless prognosis in purulent meningitis.

The development of a purulent meningitis within the dural sac of the spinal canal is a complication usually of accidents, exceptionally of operations. To prevent the ascent of the infection into the brain, Bier recommended the application of his principle of passive hyperemia in conjunction with repeated lumbar puncture. By the induction of a passive hyperemia of the brain by constriction of the neck, the pressure upon the cerebro-spinal fluid within the canal is downward, and the tendency toward an ascending infection is thus combated. In four cases of purulent meningitis, complicating gunshot wounds of the spine, after a laminectomy Klapp tried the effect of Bier's hyperemia and lumbar puncture. He attributed recovery of two of these patients directly to the combined treatment. Despite the fact that both had a serious infection, they were able to leave the field hospital 13 and 15 days respectively after the operation.

In lesions of the pachymeninges, and especially **pachymeningitis hemorrhagica interna,** Curschmann's experiences with lumbar puncture are noteworthy. He speaks of it as life-saving and curative in three cases; two of these patients were alive and in good health when the report was made three years after the puncture; the third survived six months, and died suddenly in a recurrent attack before an opportunity to puncture could be embraced.

The treatment of **tuberculous meningitis** by lumbar puncture is purely symptomatic and even though a few cases have recovered under its influence, the mere withdrawal of fluid could have no specific influence over the disease. There is no doubt of the tendency in some instances to spontaneous remissions for longer or shorter intervals, and these may sometimes have led to erroneous conclusion as to the curative effect of lumbar puncture. However this may be, it is doubtless, as Oppenheim says, the most harmless of all methods proposed, and since the prognosis is so extremely grave, puncture will continue to be employed if for no other reason than as an expedient to relieve such symptoms as headache, opisthotonos, stupor and hyperalgesia. Many have been the improvements following lumbar puncture, but complete recovery, as in the isolated instances reported by Riebald, and Stiles, must be extremely rare. According to Reichmann and Rausch, there have been recorded 18 recoveries when lumbar puncture was employed. The many failures in tuberculous meningitis following lumbar puncture are due altogether to the life history of the organism. The cerebrospinal fluid is rarely turbid and can readily be withdrawn in sufficiently large quantities, but the tubercle bacillus does not "die off" quickly as do the organisms of the

acute forms of meningitis, influenzal and the like, so that lumbar puncture can be of value only in that it relieves the effects of pressure while the defensive measures of the system are at work.

It is extremely doubtful whether the prognosis can be influenced by the injection into the subarachnoid space of iodoform emulsion, as proposed by Rossini, especially as the most prevalent sites for the exudate, the choroid plexus and the fossa of Sylvius, are so inaccessible. In a series of 105 cases, Meyer found the pressure increased in 80 per cent; he practiced lumbar puncture routinely once in 48 hours, and withdrew at each time 20 to 30 c.c. In many instances the patient brightened up, and the pulse and temperature returned to normal. Since the introduction of lumbar puncture as a routine practice, he has seen no convulsions.

The indications for lumbar puncture in **syphilis** of the brain or cord are rather limited. Its widest field of usefulness is the withdrawal of fluid for cytological and serological study, or the introduction of salvarsanized serum. In cerebral syphilis, I have resorted to lumbar puncture occasionally, sometimes to measure the pressure, and sometimes to relieve headache. Often, however, the cerebrospinal pressure is but little increased, a valuable point in the differential diagnosis between cerebral tumors and cerebral syphilis, and the results of lumbar puncture are disappointing. If, as is occasionally seen after intravenous salvarsan therapy, the pressure of the cerebrospinal fluid be increased, lumbar puncture may be used to advantage.

Is lumbar puncture indicated in all cases of **uremia?** Its effect is by no means uniform. On the part of some, notably Volhard, it has been very highly recommended, but, on the other hand, there are a number of cases in which the effects have been *nil.* There are possibly two reasons for this variability in the results: on the one hand, the variable conditions of pressure; on the other, the distribution of the cerebrospinal fluid. The cerebrospinal pressure is by no means always increased, and if it should be normal, the withdrawal of fluid could have little effect. Furthermore, Quincke has drawn our attention to the fact that the excess of cerebrospinal fluid is chiefly on the cortex and in the brain tissue, not intraventricular, and in such locations would not be readily drained away by lumbar puncture. But apart from these theoretical considerations, it is an established fact that the headache, convulsions and the coma of uremia have been favorably influenced by lumbar puncture, and when headache is severe and life threatened, other measures failing, we should not hesitate to avail ourselves of this agency.

Whether one should at any time resort to lumbar puncture in a patient with **brain tumor** is a difficult question to answer without fear of contradiction. In the pathology and in the clinical course of brain tumors we must take cognizance of the fact that there is often an associated overfilling of the ventricles and, what is of greater importance, the increased

pressure is in most instances, and to a large degree, due to the excessive accumulation of fluid. One might go still further, and say that sometimes it is almost the exclusive factor in the production of increased pressure, so small is the tumor. The possibilities of relief by lumbar puncture are unquestioned and were it not for the fact that there have been a number of sudden fatalities, directly attributable thereto, the practice of withdrawing fluid for the transitory relief it affords would meet with no opposition. There is no doubt that lumbar puncture will relieve temporarily both headache and vomiting and for that the patient is most grateful, but it will also for a while, at least, reduce the papilledema and put off the evil day when upon an insidious optic atrophy blindness supervenes. However, since the introduction of callosal puncture, we have a splendid substitute for lumbar puncture, and one which is much more lasting in its effects. Except, therefore, in unusual conditions, I have abandoned the latter procedure for its therapeutic effect, although I frequently introduce the needle to measure the pressure. I have already described the mechanism of foraminal hernia, and the characteristic blow to the respiratory center, and called attention to the greater risk of lumbar puncture in tumors of the posterior fossa. Should an occasion arise when lumbar puncture seems justifiable, it should be practiced with extreme caution and never without a manometer. The fluid should be withdrawn slowly, and only enough to reduce the pressure by one-half, never to normal. As an exceptional instance in which one may feel called upon to take this risk, I might refer to one of my patients with an inoperable tumor of the base, upon whom I had performed a subtemporal decompression. For some reason, shortly after the operation, the signs of intracranial pressure were more, rather than less, marked; possibly, because of the sudden withdrawal of pressure by the decompression and of the support to the vessel walls, there had been a hemorrhage into the tumor; possibly, following the redistribution of pressure, which I believe must occur after a decompression, the outlet to the ventricle became blocked. But whatever the cause, the signs of brain pressure increased, until the patient became stuporous, with grave Cheyne-Stokes phenomena, both respiratory and circulatory. The situation was desperate, the patient was doomed if pressure were not relieved. A lumbar puncture found the pressure 48 Hg (624 mm. H_2O) and the pressure was gradually lowered by slowly withdrawing fluid with frequent interruptions, until 25 c.c. had been withdrawn, and the pressure relieved to 20 mm. Hg. The crisis was tided over, consciousness was restored, and the signs of medullary failure disappeared. Without waiting for a recurrence of this sequence of events, I gave directions to repeat the lumbar puncture every day, until the pressure be restored to nearly normal, with these specific instructions: (1) the fluid should be withdrawn slowly; (2) with frequent interruptions; (3) with frequent pressure measurements; and (4) only

enough to reduce the pressure one-half. These instructions were carried out to the letter, and we were able to carry the patient through a crisis, which would otherwise have been fatal. The facts of this case are recited in detail, because it illustrates what I believe to be the range of usefulness of lumbar puncture in brain tumor cases. When, for any reason, callosal puncture or subtemporal decompression are positively contra-indicated, one may be driven to lumbar puncture to relieve headache or vomiting, but it should not be practiced without a realization of the dangers, or without the observance of the precautionary measures above noted.

There is another aspect of lumbar puncture with relation to brain tumor that should not be overlooked. It is perfectly true, as Quincke has said, that one cannot always distinguish between a brain tumor and a *pseudo-tumor,* the latter usually an acquired internal hydrocephalus. I have had in my clinic several striking examples of pseudo-tumors, and in these cases repeated lumbar puncture afforded prompt relief, though of only transitory duration. While there is less danger in lumbar puncture in the case of a pseudo-tumor than, for example, in tumors of the posterior fossa, I do not think we should depend altogether upon lumbar puncture, but either with decompression or callosal puncture provide more enduring relief for the pressure.

Can anything be done to avert disaster in the event of **foraminal hernia,** with impending death? Usually artificial respiration is practiced and continued until the circulation fails; it may be an hour or, as in one of my cases, twelve hours. Schottmüller says an attempt should be made to raise the pressure in the spinal canal by replacing the fluid withdrawn, or allowing sterile saline solution to flow in by gravity until sufficient pressure is maintained to disengage the brain-stem from the foramen magnum. If this be successful, it may be followed by a callosal puncture or decompression. The plan appeals to me as reasonable, and should at least be given a trial.

In **echinococcus cerebri** lumbar puncture may be of value as an aid to diagnosis, and if repeated may exert a favorable influence over the course of the disease. Hartmann discovered the true nature of the lesion in a case of cysticercus by examining the contents he removed from a cyst of the brain. And, while there is always the danger of a sudden fall of pressure, if precautions be not taken to avoid it, lumbar puncture might be used to advantage in *cysticercic disease* as a means of dealing with the resulting hydrocephalus.

As a means of relieving temporarily the immediate effects of **intracranial trauma,** *contusion cerebri,* lumbar puncture has a large sphere of usefulness. Apart from its value as an aid to diagnosis, occasions arise when for the relief of intense headache, vomiting or loss of consciousness, lumbar puncture should be practiced, and especially in those cases where there is no immediate necessity for a subtemporal decompression. I have

seen the most striking relief follow the withdrawal of fluid, which is always under extreme tension, and have no hesitancy in repeating the procedure as often as the signs of pressure call for relief.

Not only is lumbar puncture effective in the relief of pressure, but it probably facilitates the absorption of the *blood extravasations,* and in some cases, possibly by the evacuation of the serous exudate, shortens the convalescent period. Baumel has had a large experience with lumbar puncture in the European war, and has found that cases of concussion, whether or not complicated by wounds of the scalp or injuries to the head, were always accompanied with a marked increase in cerebrospinal pressure, which, in proportion to the degree of trauma, might continue for many weeks. He believes, however, as I do, that lumbar puncture should not replace decompression, favorable as its influence is upon headache, retardation of the pulse, paralysis of the cranial nerves and other symptoms of pressure.

I have never had occasion to use it for the late effects of trauma, but I can readily see how it might relieve certain pressure symptoms where the serous exudate persists. And as a matter of fact, favorable results, both transitory and permanent, have been recorded by Quincke, Weitz, Schlecht and others. In the so-called *intracranial hemorrhage of the newborn,* resort may be had to lumbar puncture to tide over a critical situation, that is, to relieve pressure, but without any hope of preventing the permanent damage to the cortex that terminates so frequently in imbecility, spastic hemiplegia, diplegia, or epilepsy. In one attempt, Audebert and Baux were able to withdraw only 3 c.c. of fluid, which was dark reddish in color. There was no change in the child's condition; it remained comatose, and died a few hours later. At autopsy there was no apparent injury to the cranium; the brain appeared normal; there were no clots, but the fluid in the subarachnoid space appeared as almost pure blood.

The results of the removal of cerebrospinal fluid from the patient in **delirium tremens** is sometimes most extraordinary. Upon anyone who has seen the mad delirium and the exhausting restlessness controlled by lumbar puncture, the demonstration will make a lasting impression. In just what way lumbar puncture exerts this beneficent influence must be left to speculation. From the facts which are known, (1) that the cerebrospinal fluid pressure is increased in most cases, and (2) that the cerebrospinal fluid contains some toxic product, one can explain the *rationale* of lumbar puncture. In some cases the improvement is to be attributed to the relief of pressure; in some to the withdrawal of toxins and the dilution of those remaining. Whether there be any advantage in attempts at dilution of the toxins with normal saline solution, as proposed by Steinbach, I am not prepared to say. The rapid replacement of the amount withdrawn by the choroid plexus would soon equal in amount

the 12 c.c. of normal saline solution which Steinbach introduced. Whatever the cause of the delirium and restlessness, in whatever way these are influenced by lumbar puncture, the fact remains that it shortens the duration of the period of delirium and in other ways influences the course of the disease.

Apart from the lesions already mentioned, where the practice of lumbar puncture is based upon some physiological principle and known pathological lesions, there is an array of diseases where, in the line of empiricism, it has been recommended as of some remedial value. Included among these may be mentioned aural vertigo of labyrinthine origin (Blake), pruritus, Ménière's disease, chlorosis, arteriosclerosis, herpes zoster, gastric crises, acute rheumatic fever, chronic nephritis, Huntington's chorea and spasmodic torticollis (Donath). In one of Abadie's cases of herpes zoster the removal of 20 c.c. of fluid by lumbar puncture was said to have had a curative effect. It has been used as a means of warding off epileptic seizures where the premonitory symptoms or aura give sufficient warning. Castin recommends it particularly as an emergency treatment in status epilepticus, and removes from 15 to 20 c.c.

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CHAPTER XIII

INTRASPINAL THERAPY

Among the many notable achievements of modern medicine, the direct application of medicinal substances to the tissues of the central nervous system in disease rightly holds an eminent position. Although the first lumbar puncture for therapeutic purposes was performed by Corning thirty-three years ago, its importance as an avenue for the administration of curative agents has been recognized and employed for less than a decade.

With a little experience and with reasonable care and attention to the few precautions necessary, the withdrawal of cerebrospinal fluid from and the introduction of medicinal substances into the spinal theca is attended with little difficulty and with a minimum of danger to the patient. While possible ill effects from properly controlled lumbar puncture are practically negligible, the great benefits to be derived both in respect to the investigation of the cerebrospinal fluid and to the introduction of curative sera may be incalculable. (See Chapter XII, on Lumbar Puncture.) The advantages of the direct introduction of medicinal substances into the subarachnoid space depend upon the circulation of the cerebrospinal fluid. There is ample evidence that many, in fact most, substances cannot pass directly from the blood into the cerebrospinal fluid. Mott, Goldmann and Swift and Ellis, with others, have shown this to be true of most drugs and all bacterial toxins. Thus, potassium iodid given by mouth, or intravenously, does not appear in the cerebrospinal fluid. Behring injected tetanus toxin into the cerebrospinal fluid of hens, resulting in typical and fatal tetanus; a like amount introduced into the vein of the hen caused no symptoms. Lewandowsky injected a few centigrams of potassium ferrocyanid into the subarachnoid space of a rabbit with toxic effect, while four to six grams injected into the jugular vein had no effect. Goldmann has shown that the choroid plexus stands guard over the cerebrospinal fluid and prevents the passage of noxious substances from the blood. Thus, following the injection of trypan blue and isamin blue into the blood, he found the choroid plexus impregnated with the dye, while none could be demonstrated in the brain, cord or cerebrospinal fluid. On the other hand, upon the injection of the stain into the subarachnoid cavity, the membranes of the brain and cord, with the exception of those of the cerebellum, the cerebral hemispheres and cranial nerves other than the optic, were diffusely stained. It would seem rational, therefore, that the

therapeutic agent should be administered directly into the cerebrospinal fluid.

Substances suitable for spinal medication are, as a rule, introduced in the form of a serum. This serum may be obtained from the patient's own blood and the desired medicament incorporated, in which case the serum is simply used as a menstruum, or the injection may consist of a highly potent, polyvalent, immune serum of foreign source, usually the horse.

Injections into the spinal theca are made by way of puncture in the lumbar region, the technic and armamentarium of which have already been considered. There are, however, certain special instruments and precautions necessary when, following the withdrawal of cerebrospinal fluid, a foreign substance is to be injected. Although the injection may be made through any lumbar puncture needle, the use of a special needle with manometric attachments for the estimation of intraspinal pressure during the withdrawal of fluid and the subsequent injection, not only places the procedure upon a more scientific basis, but obviates many dangers. The apparatus illustrated fulfills all requirements, whether introduction be made by the syringe or the gravity method. By means of the attached manometer and the three-way cock of the needle, one is able to regulate the quantity and the rate both upon the injection and withdrawal of fluids. During the injection, the flow may be stopped for pressure observation and if the intraspinal pressure be disturbed, the injection may be discontinued until pressure is adjusted (Figs. 309 and 311).

Factors of Safety in the Withdrawal and Injection.—The amount of cerebrospinal fluid to be withdrawn, and the quantity of medicinal fluid to be injected, depend upon the nature of the disease, the type of therapeutic agent employed and its effect upon the patient. The amount varies greatly in the non-purulent affections of the central nervous system. Generally it may be stated that, if possible, sufficient cerebrospinal fluid should be withdrawn to reduce the intraspinal pressure to from 8 to 12 mm. Hg before any fluid is injected. Therefore, one would expect that an amount of serum sufficient to reëstablish the former pathologic pressure might safely be introduced. While in non-purulent affections, such as tabes and paresis, this may be done with impunity, relying solely upon spinal pressure as a guide, observations in cases of purulent meningitis have shown this to be a dangerous procedure. The severe, even fatal symptoms, that may ensue should this rule be followed, are due to the increased sensitiveness of the inflamed structures, to the manipulations incident to the withdrawal of fluid and the injection of serum.

In purulent meningitis, sudden and marked changes in the peripheral blood pressure occur, both during the escape of fluid and the subsequent injection. On the other hand, in tetanus and lues, these changes are not noticeable. In purulent meningitis, therefore, these blood pressure changes

may be used as a guide to establish the limits of safety as to the amount of fluid to be withdrawn and the quantity of serum to be injected. In 1500 lumbar punctures in cerebrospinal meningitis, Sophian found blood pressure changes as constantly upon the injection of serum as upon the withdrawal of fluid. Blood pressure observations should be taken repeatedly from the beginning to the end of the procedure. Further withdrawal of fluid should cease when the blood pressure falls 10 mm. of mercury in the adult, 5 mm. in children. If the pressure begins to fall rapidly after the flow of cerebrospinal fluid has started, the rate of flow should be retarded. Occasionally this change in peripheral blood pressure will not occur, in which case as much cerebrospinal fluid should be allowed to escape as will bring the cerebrospinal pressure to normal. One would expect, upon the restoration of spinal pressure by the injection, that the blood pressure would also return to its former level. This, however, is not the case. On the contrary, the repeated estimation of blood pressure now becomes the more important, as, coincidently with the injection, the pressure continues to fall at an even greater rate than during the withdrawal. The rapidity of decrease becomes relatively greater as more and more serum is injected; moreover, the more rapid the injection, the faster and greater the fall of blood pressure. A drop in blood pressure of 20 mm. Hg is a positive indication that the injection be discontinued. Both cerebrospinal fluid pressure and peripheral blood pressure are, therefore, most important guides in the technic of intraspinal therapy. (Fig. 322.)

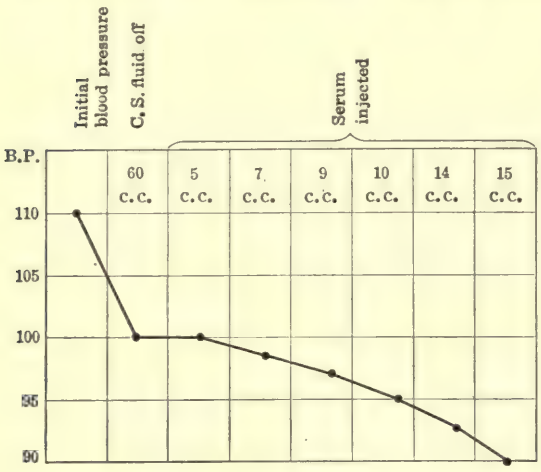

FIG. 322.—CHART SHOWING REACTION OF BLOOD PRESSURE UPON WITHDRAWAL OF FLUID AND INJECTION OF SERUM. (Sophian.)

Note fall of 10 mm. Hg upon withdrawal of 60 c.c. of fluid and the progressive fall upon the injection of serum.

TECHNIC OF INTRASPINAL THERAPY

Serum or other fluids may be permitted to flow into the subarachnoid space by gravity, or may be injected by means of a syringe. While with care and certain precautions, the latter method may be harmless, the

gravity method is the safer. With the syringe, one is apt to introduce the serum too rapidly, with perhaps alarming or even fatal results, and in spite of the utmost care, the amount of pain caused by the sudden distention of the spinal membranes upon each push of the piston is more severe than that attending the gradual and even introduction by gravity.

Whether general narcosis be indicated during puncture and injection depends upon the condition of the patient and the nature of the disease. Under local anesthesia, lumbar puncture is practically painless, but in certain conditions, general narcosis may be indicated. No special preparation of the patient or of the field of puncture is necessary beyond that which has already been described under Lumbar Puncture. The same aseptic precautions should be rigidly observed. As a precautionary measure, however, especially in the acute affections, the withdrawal of cerebrospinal fluid and the injection should be made with the patient in the reclining, never in the sitting, posture. The cerebrospinal axis should be as nearly horizontal as possible to insure uniformity of conditions for pressure observations.

Two assistants are desirable, one for taking blood pressure, the other for observing and recording the spinal pressure. On a tray close at hand should be the following articles: sterile towels or sheets for surrounding the operative area, a small medicine glass containing 5 per cent tincture of iodin for preparing the skin, small gauze sponges, a 1 c.c. Record syringe and needle filled with 0.5 per cent solution of novocain for local anesthesia, a lumbar puncture needle with rubber tubing and connections for attachment to the manometer and to the syringe or gravity container; three graduates of 10 c.c. each, two for collecting and measuring the fluid withdrawn and one containing the fluid to be injected, should the gravity method be used; and a 5 or 10 c.c. Record syringe containing the serum, if the injection method be employed. This syringe with the piston removed can be made to serve as the container for gravity administration. If one of the stock sera is to be used, the filled container will be found supplied with the outfit. Whatever the container, the serum should be warmed to about body temperature before injection; this is conveniently done by placing the container in a basin of warm water.

The blood pressure is taken and the patient placed in the proper position for lumbar puncture. The subarachnoid space is tapped at the level of the third lumbar interspace and the intraspinal pressure observed. Both blood and spinal pressure are estimated at intervals throughout the procedure. Enough cerebrospinal fluid is allowed to escape to bring the spinal pressure to normal, provided blood pressure be sustained. This will not be possible should the blood pressure fall over 10 mm. below the initial reading. In certain chronic conditions, there may be no in-

crease in the spinal pressure and, under these circumstances, reduction to 4 or 5 mm. Hg is usually a safe procedure.

Following the removal of cerebrospinal fluid, the serum is injected, and during its introduction, it is advisable to change slightly the position of the patient by raising the foot of the bed six or eight inches, or by placing a hard pillow beneath the hips. This diminishes the tendency to overdistention of the terminal cistern, at the same time permitting more rapid diffusion and distribution of the heavier liquid throughout the lighter cerebrospinal fluid. If the serum be administered by syringe, the procedure is extremely simple. A Record syringe of 5 or 10 c.c., depending upon the amount to be injected, with a smoothly working piston, is connected with the side vent of the three-way cock of the spinal needle. It is best to interpose two or three centimeters of rubber tubing between the syringe and needle. This gives a measure of latitude so that sudden, uncontrolled movements of the patient are less likely to result in pain, breakage or displacement of the needle. The injection should be made slowly and evenly, and while the rate of flow may be controlled by observing its effect upon the blood pressure, not more than one and a half cubic centimeters should be injected per minute.

By far the safer means of administration, all things considered, is the gravity method. An ordinary glass funnel, or the barrel of a 10 c.c. Record syringe containing the serum, is connected by means of proper metal tips and 20 cm. of rubber tubing with the side vent of the needle. The stock sera of some pharmaceutical houses are furnished in sealed containers with the tubing attached for connection with the needle. The serum is allowed to flow from the container until the tubing is filled, the connection is made, the valve on the needle opened and the fluid allowed to flow by gravity. By raising or lowering the container, the rate of flow is nicely adjusted, and if untoward symptoms arise which necessitate the removal of a part of the injected serum, this is readily accomplished by lowering the container below the level of puncture, thus permitting the fluid to siphon off.

While the *pain* of lumbar puncture itself is negligible, that occurring during the injection of substances into the spinal canal is often severe, and at times, agonizing. Referred to the back, legs and abdomen, particularly the knees, pain occurs as soon as the injection is begun and, while it usually subsides immediately after the injection ceases, it may persist for hours. It is less marked when the serum is of proper temperature prior to the injection. For the relief of pain, Sophian suggests what he terms "water anesthesia," which appears, for some unknown reason, to alleviate greatly the pain and restlessness. During the injection the patient is encouraged to sip water through a tube or straw. Morphin, or one of its derivatives, may be necessary.

Shock and collapse may occur if too much cerebrospinal fluid be

withdrawn or the injection made too rapidly, with undue pressure or in excessive quantities. Shock and collapse are due to sudden and marked changes in intraspinal pressure and should not occur if proper precautions be taken, particularly, if one heed the warning which is afforded by the blood pressure changes. Associated with marked fall in blood pressure, there may be in addition stupor, which deepens as the blood

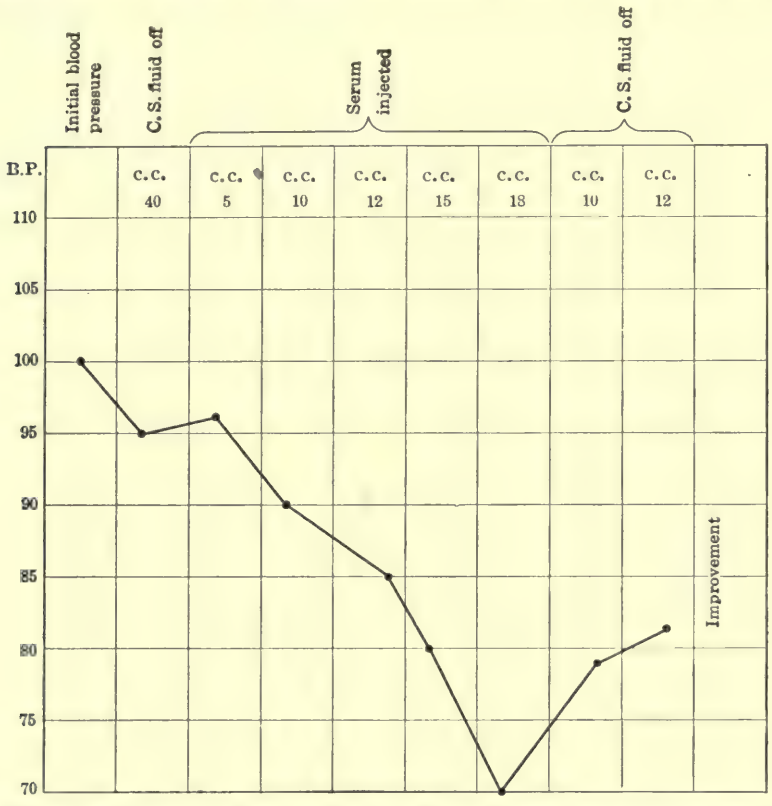

FIG. 323.—CHART SHOWING MARKED FALL IN BLOOD PRESSURE ACCOMPANIED BY SYMPTOMS OF SEVERE SHOCK, RESPIRATORY EMBARRASSMENT AND INCONTINENCE OF BLADDER AND RECTUM. (Sophian.)

Note the immediate elevation of blood pressure and general improvement upon the withdrawal of fluid from the canal.

pressure falls, superficial and irregular or deep, stertorous, slow and irregular breathing, or even cessation of respiration. The pulse is variable, but may continue of good quality even when the pupils dilate. Incontinence of feces and urine, accompanying a drop in blood pressure, should be interpreted as a warning. When the blood pressure falls over 20 mm. of mercury, the injection should be discontinued, and if there be a greater fall, with the appearance of any of the above symptoms, fluid should be withdrawn from the canal at once (Fig. 323). If breathing stops, ar-

tificial respiration must be resorted to and atropin and cocain given hypodermatically in full doses.

That *anaphylactic symptoms,* serum sickness, may and do frequently occur after the repeated injection of sera into the spinal canal, cannot be disputed. This statement applies only to the injection of foreign sera. The symptoms, seldom alarming, although very annoying, are encountered in from 50 per cent to 60 per cent of the cases thus treated. They commonly appear about one week after the first injection, although in persons previously sensitized by the administration of serum for other purposes, or in asthmatics, anaphylaxis may manifest itself within a few minutes of the injection. Headache, vertigo, nausea and vomiting, and slight fever with a general urticarial eruption are the common evidences of this complication. In place of the urticaria, however, may appear a general erythema or angioneurotic edema which usually persists from a few hours to three or four days. While this is the usual sequence of serum administration, at times, the reaction is much more severe and may be alarming. The prostration may be marked with severe chills, alternating with high temperatures, or may exhibit the weak, feeble pulse and cold, clammy skin of shock. As these phenomena may occur in acute meningitis, it is difficult sometimes to tell whether they are due to the serum or to the disease.

The treatment of serum sickness is eliminative and supportive. Atropin or belladonna will occasionally abort the attack. Laxatives and a soft liquid diet are indicated; sedatives may be necessary.

An *aseptic meningitis,* presenting all the characteristics, clinical and pathologic, of the acute suppurative type, but without the discovery of an infecting organism, is recognized as a complication of intraspinal therapy. It may occur during the treatment of tetanus, syphilis of the central nervous system, or even following the introduction of magnesium sulphate or other anesthetic substances. The causes are both chemical and biologic and the symptoms usually appear in from eighteen to twenty-four hours following the injection. The patient becomes restless and anxious, at first with normal temperature and pulse, to be followed shortly by high temperature, rapid pulse, extreme headache, delirium and perhaps unconsciousness, which may persist for some time. All the physical signs of meningitis are present, including rigidity of the muscles of the neck and back and the Kernig sign. Lumbar puncture is positively indicated; the spinal pressure will be found high, the fluid cloudy, and sufficient fluid should be withdrawn to reduce the pressure to normal. This should be repeated as often as the pressure symptoms return. While this complication is alarming, if the spinal pressure can be restored to nearly normal limits, in the majority of cases the symptoms gradually subside without complication or sequelæ and fatalities are rare.

INTRASPINAL TREATMENT OF MENINGITIS

Epidemic Cerebrospinal Meningitis.—With the possible exception of diphtheria, in no disease has the discovery and application of a specific remedy been of greater benefit than in epidemic cerebrospinal meningitis. Prior to the introduction of antimeningococcic serum, there was no accepted method of dealing with this disease, the mortality of which ranged from 70 to 90 and often 100 per cent with its train of serious sequelae.

The Diplococcus of Weichselbaum was discovered in 1887, but not until 1904 and 1905 was it proved beyond question of doubt to be the sole cause of the disease. Search at once began for a specific serum and

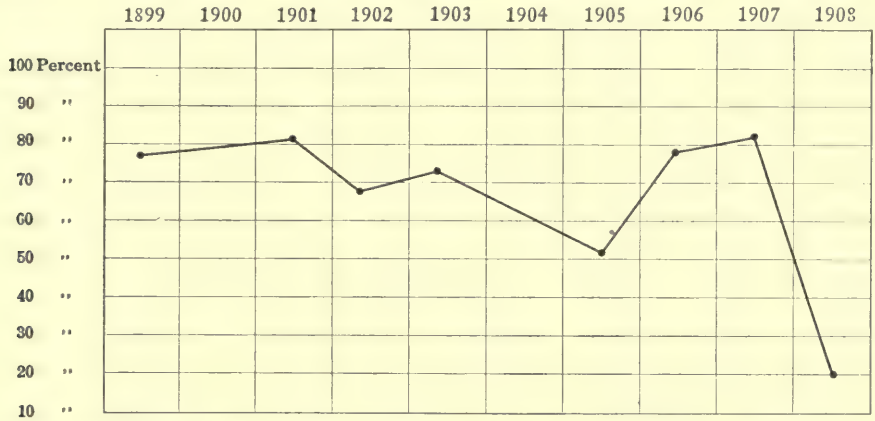

FIG. 324.—GRAPHIC CHART SHOWING MORTALITY PERCENTAGE PRIOR TO AND FOLLOWING THE INTRODUCTION OF ANTIMENINGOCOCCIC SERUM.

almost identical results were coincidentally announced by Jochman in France, by Kolle and Wassermann in Germany and by Flexner in the United States. From this date, 1904, to the present, continued use of the serum has but substantiated the early reports as to its efficiency and reliability.

The opportunity for the use of Flexner's serum was first offered in the United States in May, 1907, at Akron, Ohio, and striking results were obtained, the mortality rate falling at once from 90 to 25 per cent. The latest report, based upon an analysis of 1295 cases, shows a mortality of only 30 per cent in all parts of the country, under various conditions, at all ages, and in the hands of many operators. Of 125 cases in infancy where, prior to the use of the antimeningococcic serum, the mortality was extremely high, often 100 per cent, 63 recovered after the employment of Flexner's serum.

The direct administration of antimeningococcic serum into the sub-

arachnoid space inhibits the growth, initiates the disintegration of the diplococcus, and at the same time encourages phagocytic activity. While its bactericidal effect is the most important, the endotoxin is also rendered innocuous by phagocytic digestion. As the serum cannot enter the cerebrospinal fluid by way of the circulation, its introduction subcutaneously or intravenously is without effect, except in cases of a generalized meningococcic septicemia, when 20 to 30 c.c. of serum may be given intravenously to supplement the intraspinal dose.

For the best results, a proper polyvalent immune serum should be selected and administered intraspinally at the earliest possible moment. The element of *time* is most important, not only from the standpoint of actual mortality but because of the effect of the serum in limiting the duration of the disease and controlling the sequelae. There are several reliable sera on the market, and if the result of using one brand in a particular case be unsatisfactory, another should be tried, and even a third. In any widespread epidemic, it is advisable to use a serum made from the organism recovered from the individual patient.

TABLE I.—INFLUENCE OF TIME OF FIRST INJECTION UPON MORTALITY

Day of Disease When Treatment Began	Flexner 1211 Cases	Dopter 402 Cases	Netter and Debre 99 Cases	Sophian 161 Cases
In first three days...	18 per cent.	8.2 per cent.	20.9 per cent.	9 per cent.
Four to seven days	27 " "	14.2 " "	33.8 " "	14.9 " "
After one week....	36 " "	24.1 " "	26 " "	22.6 " "

Although injections of serum are made, ordinarily, every twenty-four hours, this should not interfere with the more frequent use of lumbar puncture as often as pressure symptoms manifest themselves. The withdrawal of fluid, always to be carefully controlled by blood pressure and cerebrospinal pressure observations, is a valuable therapeutic measure in relieving the excessive intracranial pressure and removing a great number of organisms and their toxic products. This in itself is often life-saving, while in other less serious forms of meningitis, simple repeated lumbar puncture not only gives marked improvement but may lead to ultimate recovery. The value of lumbar puncture is graphically illustrated in the case of a child aged six, reported by Souther. Two lumbar punctures were made with the withdrawal of purulent fluid containing meningococci. It was impossible to procure antimeningococcic serum. Nevertheless, improvement after the punctures was rapid and followed by early recovery. During the first twenty-four to forty-eight hours of the disease, the cerebrospinal fluid is often clear, while later it becomes turbid. It is during this early period, when lumbar puncture still reveals a clear fluid, that the best results are obtained from the serum treatment.

Antimeningococcic serum may be administered either by the *syringe* or *gravity method.* The latter is to be preferred, since by this method the fluid is injected neither too rapidly nor in too large quantities. Should untoward pressure symptoms unfortunately appear during the injection, the container may be lowered, allowing the serum to drain back into it

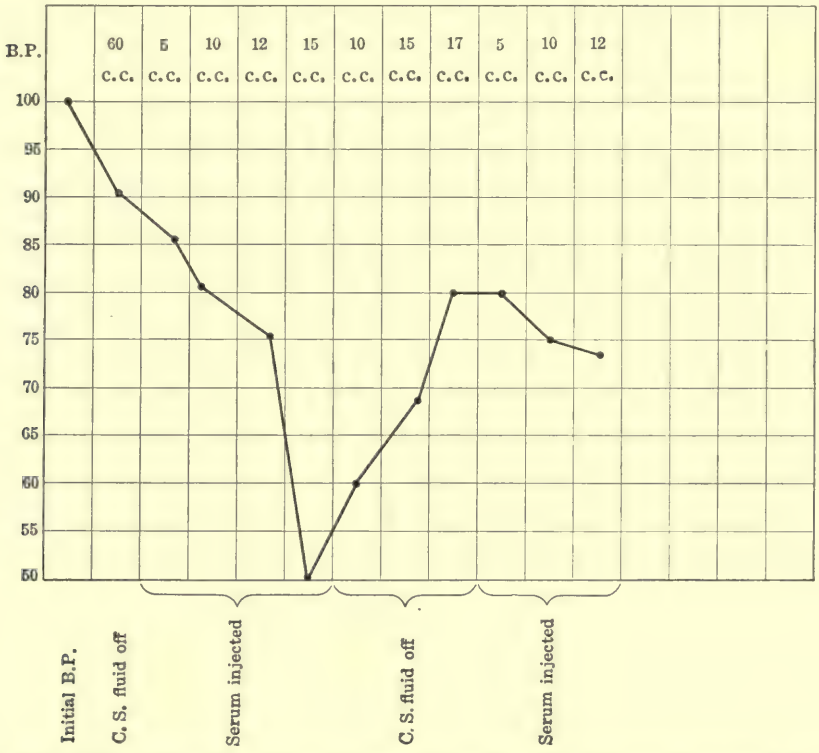

FIG. 325.—BLOOD PRESSURE RECORD DURING INJECTION OF ANTIMENINGOCOCCIC SERUM BY GRAVITY.

Note the very rapid fall of blood pressure with severe symptoms following injection of a small dose of serum. Symptoms were relieved and pressure immediately rose on removal of all of the serum injected. Serum reinjected, causing only moderate drop in pressure.

from the spinal canal. Very often, after a few minutes have elapsed, the container can again be raised and the serum reinjected very slowly and carefully, controlled by its effect upon the blood pressure until the desired amount is administered. If pressure symptoms occur during the injection with the syringe, the latter must be quickly disconnected from the needle, permitting the fluid to escape from the canal. Thus the serum is lost and reinjection is impossible. We do not approve of the advice sometimes given under these circumstances to withdraw fluid from the canal by suction with a syringe, as the cord or roots of the cauda equina may be damaged by being drawn forcibly against the point of the needle.

If possible, at least 30 c.c. should be injected into an adult. The following is the average dose at different ages:

1 to 5 years	12 c.c.
5 to 10 years	15 c.c.
10 to 15 years	20 c.c.
15 to 20 years	30 c.c.
20 and over	40 c.c.

The *number of injections* given and their frequency depend upon the time treatment is begun, the severity of the infection, the condition of the patient, and the changes produced in the cerebrospinal fluid. In fulminating cases, injection may be repeated in twelve hours, but ordinarily twenty-four hours should elapse between treatments. While four injections in all are often sufficient, they should be repeated until the diplococci disappear from the cerebrospinal fluid and the general symptoms have subsided. This may prolong the treatment over a considerable length of time, as in a case reported by Netter, whose patient recovered after the administration of 823 c.c. of serum in 22 injections. The cerebrospinal fluid should be examined at each lumbar puncture, as the results of this examination determine the course of treatment. In favorable cases, first the diplococci free in the fluid disappear, then the intracellular organisms undergo degenerative changes, disintegration and autolysis with the complete disappearance of the bacteria. The cerebrospinal fluid becomes clearer and its pressure nearly normal, the leukocytes disappear, while in the blood leukocytosis makes way for a normal count. At the same time, there is a general symptomatic improvement, the nervous manifestations abate, the fever subsides, and the circulation returns to its normal state. Until these changes take place, the use of the serum should be continued.

During the injection, the foot of the bed should be elevated six to eight inches, or the hips of the patient raised on pillows. This prevents undue distention of the cisterna terminalis, while it favors the more rapid diffusion of the heavier serum with the lighter cerebrospinal fluid. With the exception of a few minutes immediately following injection, the head and shoulders of the patient should be kept slightly elevated.

In certain virulent *fulminating types* of epidemic cerebrospinal meningitis, the fluid may rapidly become so thick from accumulated inflammatory exudate that it will not flow from the lumbar puncture needle. These are the most severe cases and require heroic and what at other times would be considered unwarranted procedures. Thus an attempt should be made to irrigate the canal by injecting small quantities of normal saline solution through the lumbar puncture needle, or a secondary puncture may be made at a higher level and the salt solution introduced

through the upper and drained off by the lower needle. In this manner, a certain amount of exudate may be removed. If this fails, however, the injection of serum should not be withheld. Small quantities, 8 to 10 c.c., should be administered even under pressure and the injection repeated every six, eight or ten hours until results are obtained.

In a small number of cases the injection of serum is apparently followed by a diminution in the quantity of cerebrospinal fluid and, while the fluid withdrawn may be so clear as to suggest a favorable progression of the case, signs of intoxication may persist. This is probably due to the inaccessibility of certain numbers of diplococci in isolated areas of the membranes, or in the obstructed cerebral ventricles. Accessible meningococci cease multiplying usually after the second or third injection, and not infrequently after the first injection. If symptoms persist with an apparently normal fluid, and if a posterior basal meningitis can be eliminated, small doses, even under pressure, frequently repeated, should be continued until improvement ensues.

While distention of the subarachnoid space and ventricles is present in all cases of epidemic cerebrospinal meningitis, the pressure symptoms are usually relieved by lumbar puncture and serum administration. Occasionally, however, while the spinal fluid and general symptoms of toxemia may improve, alarming signs of an *acute internal hydrocephalus* may supervene and call for immediate treatment. This complication is due to interference with ventricular drainage by plastic exudate or inflammatory reaction, and calls for ventricular puncture with injection of serum directly into the ventricles. While in infants this may be accomplished by simple puncture with the needle through the anterior fontanel, it is unlikely that permanent drainage may be secured in this way, and the symptoms recur within a few hours. Permanent drainage may be secured by callosal puncture, after the method of Anton, on one or both sides. This not only prevents ventricular distention, but facilitates the diffusion of the serum administered subdurally either into the cranial or spinal subarachnoid space.

In untreated cases, or where treatment by serum during the acute stage has not been sufficiently active, the disease may pass into a subacute or chronic stage. Symptoms of hydrocephalus usually predominate, while those of intoxication may be slight. Repeated lumbar puncture, if the ventricles be not blocked, should be practiced until the spinal pressure remains normal. If there still remain diplococci or leukocytes in the spinal fluid, the serum treatment should be continued. Although rare after the proper administration of serum, relapses occur in about 5 per cent of cases and must be treated by an additional series of serum injections. As has been shown by the experiences of Netter, Debre, Hammond and others, there is no arbitrary limit to the amount or number of injections that may be given in any individual case.

The intraspinal injection of antimeningococcic serum is commonly followed immediately by severe *pain* in the back, legs and abdomen. If the syringe method of injection be used, the pain following is often more intense, while exacerbations during injection occur with each thrust of the piston. If pain persist, local hot applications and the administration of morphin, or one of the opium derivatives, are indicated. The occurrence of shock and collapse during injections has already been considered with their cause, prevention and treatment. With the gravity method and by careful observation and control of blood and spinal pressure, these com-

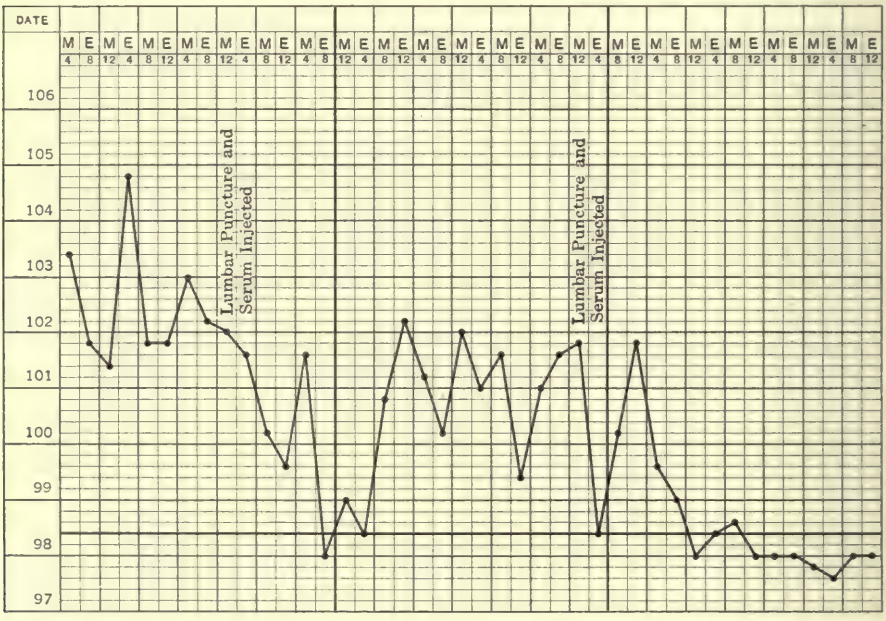

FIG. 326.—CLINICAL RECORD SHOWING TEMPORARY FALL IN TEMPERATURE DUE TO LUMBAR PUNCTURE, THE INITIAL RISE AND SECONDARY FALL AFTER SERUM INJECTION.

plications are rare. With the rapid bacteriolysis and liberation of toxins following serum injections, the temperature not infrequently rises suddenly. This initial rise rarely persists beyond two or three hours, and is followed by a fall in temperature below that preceding the lumbar puncture.

Previous to the discovery of antimeningococcic serum, the lowest *mortality* from the disease in any year was 58 per cent, while in most epidemics it ranged between 70 and 90 per cent. While the results of the serum treatment have not been uniformly good, the very marked and immediate reduction in mortality following its introduction was striking. The death rate at once fell from 90 per cent to below 25 per cent, and among certain groups of cases to 10 per cent. In 1908, 21 cases

were reported with a mortality of only 14 per cent; at the same time, 40 cases were reported with a death rate of but 22 per cent. When the serum was used the first week, the mortality was but 8 per cent; if withheld until after the second week of the disease, it rose to 77 per cent. The greatest factor influencing the effect of serum treatment is the time of the initial injection. In the latest report of 1295 cases treated with intraspinal injections of serum, the mortality was 30 per cent, including cases of all ages. In the epidemic of 1916 in England, although the serum was widely used, the death rate remained above 50 per cent. Two factors may account for this high rate of mortality, other things being equal, an impotent serum or a parameningococcic type of organism.

Striking as is the effect of serum therapy upon the mortality, its effect upon the *course* of the disease is even more so. Without serum therapy, recovery from the disease is slow and protracted, often characterized by gradual subsidence of symptoms, of which rigidity of the muscles of the neck and the back persists after the others disappear. Under intraspinal injections of serum, however, about 30 per cent of cases terminate by crisis. The average duration of the disease in 774 cases collected by Flexner was 11 days; in those terminating by crisis, 5.7 days; by lysis, 14.3 days. This is in striking contrast to the untreated cases in which the average duration is 4 weeks.

As our experience with the intraspinal administration of antimeningococcic serum increases, so does the truth of Flexner's statements become the more evident, that when used by the intraspinal method, it is capable of reducing the duration of the illness, of preventing in large measure the chronic lesions and types of the infection, of preventing such complications as deformities, mental deficiencies, deafness and blindness, of bringing about complete restoration of health in all but a very small number, and of greatly diminishing the fatalities.

Parameningococcic Meningitis.—While in the majority of instances of epidemic meningitis, the results of treatment with antimeningococcic serum have been eminently satisfactory, it became evident, as experience with its use widened, that during treatment a certain number failed to react favorably, that injections of the serum, instead of causing an amelioration of symptoms and fall in temperature, were followed by intensification and that instead of the usual effect upon the organisms, the meningococci in the cerebrospinal fluid continued to multiply and failed to be affected by the leukocytes. These phenomena were observed particularly in isolated cases and in fresh epidemics.

Further study of the organism present in such cases, the so-called parameningococcus, showed that it was culturally indistinguishable from the true or normal meningococcus, but that serologically it exhibited differences as regards agglutination, opsonization and complement deviation. This parameningococcus, according to Dopter and other French

investigators, invades the meninges and blood, and is believed to be one of the causes of cerebrospinal meningitis. Dopter produced an antiparameningococcic serum in 1912, and its use was promptly followed by the recovery of cases of meningitis caused by the parameningococcus.

While most of the sera procurable on the market are polyvalent, containing the antibodies for the parameningococcus, as well as those for the ordinary organism, it is quite possible that when this coccus is the sole causative agent, these polyvalent sera may not be effective. If this be the case, the organism, following injection of the antimeningococcic serum, still remains extracellular and the local and general symptoms persist. Under these circumstances one should not wait until the cultural and serological tests are completed before resorting to the use of a parameningococcic serum or at least of a mixture of the two sera.

The amounts and methods of administration of the antiparameningococcic serum do not differ from the course already advised for the use of antimeningococcic serum. While the same opportunity for observing the results of serum treatment in parameningitis has not been possible owing to its comparative infrequency, there seems no reason to conclude that they are any less remarkable than in the meningococcic variety of the disease.

Streptococcic Meningitis.—In addition to repeated lumbar puncture, the antistreptococcic serum may be used, it being borne in mind that the meninges are unusually sensitive to manipulation of any sort and that extraordinary care is required both in the withdrawal of fluid and in the injection of serum. In no type of meningitis is the guidance of the blood pressure and the cerebrospinal pressure of greater importance. The withdrawal of fluid should be very gradual and its effect carefully observed. The antistreptococcic serum is injected preferably by the gravity method at the rate of not more than 1 c.c. per minute. As in meningococcic meningitis, as much serum as possible under blood pressure guidance should be injected at each treatment and the dose repeated at least every twenty-four hours until favorable effects are noted. The second injection is given preferably in twelve hours.

No matter what the treatment, this disease is well nigh hopeless. Of four cases of recovery of which I have knowledge, two were treated by repeated lumbar puncture alone, one with lumbar puncture combined with the intraspinal injection of the serum and one by drainage of the basal cysterna.

Staphylococcic Meningitis.—While the mortality of staphylococcic meningitis is not so high as the streptococcic, the intraspinal treatment of the disease is in the same state of hopeless ineffectiveness. Should, however, the serum be used, the technic for its intraspinal administration differs in no material way from that described for antistreptococcic serum, other than the substitution of the appropriate serum.

Influenzal Meningitis.—As a result of the more frequent use of lumbar puncture and routine bacteriological examinations, this form of meningitis has proved not uncommon. The search for an immune serum was early rewarded by the production of such a serum by Flexner and Wollstein in 1913. This serum has been definitely proved by them to be effective in the cure of influenzal meningitis experimentally produced in monkeys; and clinical evidence, slowly accumulating from various parts of the country, shows it to be efficacious in the human being. The anti-influenzal serum is prepared in a manner similar to that of the antimeningococcic serum by injections into the horse, first of non-virulent, later of virulent, cultures of the organism. These injections, extending over many months, result in the production of a serum with high agglutinative and bacteriotropic powers, but lacking in bacteriolytic properties.

The death rate of influenzal meningitis is high. In a series of 88 cases there were only 8 recoveries (Torrey). Hence every agency for good should be employed. In all cases of meningitis, one should bear in mind the possibility of hydrocephalus or pyocephalus as sequelae. When there is a sudden decline in the number of organisms or cells with a lowering in pressure, when after the daily withdrawal of large quantities of fluid, clear or turbid, but a few drops or no fluid at all are found in the terminal cistern, an acute hydrocephalus or pyocephalus should be suspected, and, especially if the symptoms continue, the question of callosal puncture should be given serious consideration.

To derive any benefit from the use of anti-influenzal serum, its administration must be begun at the earliest possible moment in the course of the disease, hence the necessity of early lumbar puncture and careful bacteriological examination in every instance where meningitis is suspected. Inasmuch as the meningeal infection is usually secondary to a bacteremia, intravenous administration of the serum should accompany its direct introduction into the spinal theca. Subarachnoid injection is done by the gravity method in exactly the same dosage and under the same precautions as in epidemic meningitis. Its favorable action is shown by a gradual return of the cloudy cerebrospinal fluid to its normal state, by the evidences of leukocytic ingestion, in the appearance of intracellular organisms and by the diminution in number of leukocytes, both in the blood and cerebrospinal fluid. While the virulence of the bacteria is immediately affected, their complete disappearance is much less rapid than in cerebrospinal meningitis.

Pneumococcic Meningitis.—The invasion of the meninges by the pneumococcus is by no means uncommon. It occurs more frequently than influenzal meningitis and is followed by at least as high a mortality as the latter. The use of antipneumococcic serum in the treatment of pneumococcic meningitis has not been very encouraging. This is due, in part, to the fact that as yet a polyvalent pneumococcic serum has not been

produced, while in each individual infection an homologous serum for the particular strain of the organism present is necessary. If that particular type has not been used in the production of the serum obtainable, the intraspinal injection of the latter will have little or no effect. Experimentally, even with the proper serum, the results have been very disappointing. It has been found, however, that the addition of sodium oleate and boric acid to the serum greatly increases its bacteriolytic properties and renders results more certain.

In explanation of the action of sodium oleate it has been shown that the complex fatty acids and their alkaline soaps may be obtained both from tissue cells and from leukocytes and as a result of autolysis, and that these acids and their soaps are both bactericidal and hemolytic. That these soaps occur in inflammatory foci has been shown by Klotz, and their origin explained by the investigations of Achaline as due to the presence of lipase. In this manner is explained the well-known phenomenon of the lowered virulency and even death of the infecting organisms. The effect of soaps was first investigated by Lamar and decided results were obtained by him. Pneumococci were quickly killed by sodium oleate in 0.5 per cent solution, while their virulency was greatly reduced by even 0.1 per cent solution, and furthermore, the addition of these weaker solutions rendered the organisms much more susceptible to the bacteriolytic properties of an homologous antipneumococcic serum. It was found, however, that the addition of some substance preventing the union of the protein of the serum with the oleate was necessary; otherwise, this protein content inhibited or destroyed the lytic powers of the soap. Liebermann and Fenyvessy found that boric acid would successfully prevent this action of the protein. Experimentally, this combination of an homologous antipneumococcic serum with sodium oleate and boric acid has been effective.

As in all forms of meningitis, the prompt administration of the serum is the first requisite in its successful treatment. The addition of sodium oleate and boric acid must be made to the ordinary commercial serum at present obtainable. In preparing 20 c.c. for one administration, the three constituents may be combined in the following proportions:

Antipneumococcic serum (sterile)	4 c.c.
5 per cent aqueous solution of boric acid (sterile)	15 c.c.
2 per cent aqueous solution of sodium oleate (sterile)	1 c.c.

The injection of this mixture into the subarachnoid space should be done by the gravity method, following the withdrawal of cerebrospinal fluid. Both the withdrawal of fluid and the subsequent injection should be carefully guided by observing their effect upon the blood and cerebrospinal pressures.

Tuberculous Meningitis.—In numbers of instances, the re-injection

of fluid or serum aspirated from serous cavities, the seat of infection by the tubercle bacillus, has been followed by general and local improvement. These effects have been observed particularly in tuberculosis of the pleura and peritoneum, a considerable number of instances of which have been reported showing marked improvement, and in some, apparent recovery. A like procedure has been suggested in the treatment of tuberculous meningitis, especially in the subacute and chronic types of the disease. However problematical its benefits may be, it is at least relatively harmless, and every patient suffering from this almost hopeless and highly fatal disease should be given the benefit of the doubt.

The cerebrospinal fluid withdrawn by lumbar puncture is allowed to collect in a sterile vessel. Enough fluid is permitted to escape to lower the spinal pressure, if possible, to about 4 or 6 mm., the blood pressure change determining the limit of withdrawal. To this fluid is added an equal quantity of 2 per cent sodium citrate in normal saline solution and the whole heated at 60° C. for one hour. A few drops of a 5 per cent phenol solution is then added as a preservative to the mixture, which should be kept in a sterile flask until used. The injection of this autoserum is made subcutaneously in doses varying from 0.5 to 2 c.c., depending upon the condition and age of the patient. Its beneficial action may be due to the presence of aggressins, bacteriolytic amboceptors, complements or endolysins or to the stimulation of a leukocytosis. It is more likely that the serum, with its tubercle bacilli and their products, acts in the rôle of a vaccine.

A sharp reaction with rising temperature, possibly accompanied by chill, lassitude and diuresis, rarely diarrhea, follows the subcutaneous injection of the cerebrospinal fluid. This rarely persists for longer than a few hours and need cause no anxiety. It may be repeated in from two to three days in the same, or slightly increased, dosage and thereafter at like intervals, depending upon the condition of the patient and the effects of the treatment.

INTRASPINAL TREATMENT OF TETANUS

In 1890, Behring and Kitasato found that animals could be immunized against the tetanus bacillus and its toxin and that the blood of these animals acquired a new property, in that when it was injected in suitable quantity into other animals, the latter were protected against doses of tetanus toxin which otherwise would have been fatal. The antitoxin is contained in the blood serum and as such is used both for the prophylaxis and the treatment of tetanus.

The serum is standardized in units on the basis of its antitoxic potency, each unit containing ten times that amount of antitoxin which

is required to preserve the life of a standard guinea pig for ninety-six hours after the guinea pig has received, by injection, the test dose of tetanus toxin. The quantity of toxin in this test dose is one hundred times greater than the smallest lethal dose which would be capable of causing the death of a guinea pig within ninety-six hours. It will be seen, therefore, that the standard unit of antitoxin possesses great neutralizing power, and is capable of rendering inert a massive dose of the toxin.

It is important to remember that antitetanic serum is an antitoxin and possesses no bactericidal properties, nor has it the power to inhibit the growth of the organisms. Exactly how the antitoxin acts upon the toxin is not known. The idea that its action is a direct chemical one has been abandoned. It appears to be able not only to neutralize the toxin present in the circulating blood, but also to loosen or draw out the toxin bound in the cells of the central nervous system, provided it can be brought into immediate contact with these elements through the medium of the cerebrospinal fluid. Krauss and Amiradzibi have shown that the toxin must pass out of a poisoned nerve cell into the surrounding tissue before it can be neutralized, as the antitoxin cannot penetrate the cell. This has been used as an argument against the intraspinal use of the serum. That this argument is fallacious, however, has been shown by the further demonstration that the rate of diffusion of the toxin out of the containing cell is accelerated by the presence of antitoxin in the surrounding fluid. Moreover, von Graff and Metschnikoff have shown experimentally that it is possible to extract tetanus toxin from the cells of the liver by means of antitoxin.

After huge doses of antitetanic serum have been administered intravenously, only the smallest trace can be discovered in the cerebrospinal fluid. If, therefore, any effect is to be obtained on the toxin, which has already reached the central nervous system, it seems reasonable to expect this only after the antitoxin has been introduced directly into the cerebrospinal fluid.

While tetanus antitoxin has proved most efficacious in the prevention of tetanus, its employment as a curative agent has been much less successful, chiefly due to its late administration, insufficient dosage and the method of administration.

The tetanus bacillus remains and multiplies at the site of infection, while the toxin there produced is absorbed and carried to the central nervous system, the action upon the cells of which produces the symptoms so characteristic of the disease. A part of the toxin travels by way of the motor neurons of the infected region directly to the spinal cord. By far the greater part, however, gains access to the blood, by which it is carried to all parts of the body, and from the end plates of all the motor nerves, again ascends along the axis cylinders or their lymph channels to the cells of the cord. It is clearly seen, therefore, that not only the toxin

circulating in the blood but also that which has reached and entered the cells of the cord must be attacked and destroyed. To accomplish this, tetanus antitoxin has been administered subcutaneously, intraneurally and intravenously. The latter method is the most efficacious for neutralizing the circulating toxin, because it is the most rapid; but only by the intraspinal method have we the least chance of influencing directly the already poisoned cells of the cord.

As the infecting organisms remain strictly localized in the tissues of the wound of entry and there elaborate the toxin, which by various channels enters the tissues of the central nervous system, the treatment should be directed at first toward their eradication; all parts of the wound should be laid freely open, all foreign material and necrotic tissue removed and the wound thoroughly disinfected with a chemical or with an actual cautery. Further efforts in the destruction of the organism consist in the constant application to the wound of agents of known bactericidal properties, the most efficacious of which, as shown by the work of Carrel, Chatro, DePage and others, is the hypochlorite solution of Dakin. If properly applied, according to the technic of Carrel, the solution is capable, without harm to the tissues themselves, of killing all organisms, anaerobic as well as aerobic, with greater certainty than any other known bactericide which is safe to use on living tissues.

Once the diagnosis is established, 10,000 to 20,000 units of antitoxin are immediately injected intravenously and a like, or even larger, quantity is given by subcutaneous injection. These injections, one or both according to the course of the disease, may be repeated in two or three days if necessary, in the same dosage, but if the symptoms abate, reducing the amount from 10,000 to 15,000 units. In severe cases, intraneural injections are indicated and seem to have been beneficial in some instances. This method of administration has as its object the neutralization and the blocking off of the toxin as it ascends within the sheaths of the motor nerves. Under light, general or local anesthesia, the large motor nerve trunks enervating the region of the infected wound are exposed, and into their sheaths the antitoxin is injected; from 1,500 to 3,000 units may be given in this manner. These intraneural injections, which involve the giving of an anesthetic and in some instances an extensive dissection, are not altogether without objectionable points and should be abandoned in favor of the other available methods, provided treatment be instituted early and the serum has been given in sufficient quantities by the other routes.

The intraspinal use of antitetanic serum was first suggested by Jacob in 1898, and much more satisfactory results have been obtained since its institution. Hofmann has reported a series of thirty cases from the clinic of von Hacker. In treating the first fourteen of these, the subcutaneous route alone was used with a resulting mortality of 58.3 per cent.

In the remainder, in addition to the subcutaneous administration, intraspinal injections were used, with the result that the mortality fell to 12.5 per cent. Not only clinical results such as those of Hofmann, but the opinions of all experimental observers are united as to the efficacy of the intraspinal treatment. It should be clearly understood that the subarachnoid administration of antitetanic serum does not replace the other methods of attack or the symptomatic management of the disease.

Intraspinally, antitetanic serum may be given either by the syringe or the gravity method. While guidance by blood pressure in the tapping and injection is desirable, it is not so necessary as when dealing with acute inflammatory lesions of the meninges and may safely be omitted. Sufficient cerebrospinal fluid is withdrawn to lower the spinal pressure to normal before making the injection. Owing to the hypersensitiveness of the central nervous system to all external stimuli, it is desirable, in fact necessary, when doing lumbar puncture in tetanus to employ a general anesthetic during the withdrawal of the fluid and the injection of serum. Depending upon the age of the patient, from 3,000 to 5,000 units should be given at each intraspinal injection. Sufficient sterile normal saline solution is added to the serum to bring the quantity to be injected up to 10 or 15 c.c. and the whole warmed to body temperature before introduction. Co-incidentally with the subarachnoid injection, from 10,000 to 20,000 units of the antitoxin are given intravenously.

Antitetanic serum introduced into the spinal theca quickly finds its way into the general circulation. This necessitates the repetition of injection every twenty-four hours until beneficial effects are obtained. The blood, on the other hand, retains its highly antitoxic qualities for several days, which obviates the necessity for repeating the intravenous administration so frequently. In order, however, to amplify this antitoxic content of the blood, 10,000 to 20,000 units of the serum should be given subcutaneously four or five days after the first injection. As a rule, after the first intraspinal injection, there results an exacerbation of the symptoms, reaching a maximum in twenty-four to thirty-six hours, after which gradual improvement may take place. After each injection there is a reaction consisting in a rise of temperature of from 1.5° to 2° C., which lasts for ten or twelve hours, and following this reaction there is more or less distinct improvement of all the symptoms, especially as regards the clonic attacks.

That the lowered mortality of tetanus is due to the intraspinal administration of the serum, admits of no reasonable doubt. When one considers that by the time the first signs of tetanus appear, a fatal dose of toxin either has been absorbed and fixed, or, if not completely fixed, has become inaccessible except to direct intraspinal treatment, the value of the latter is clearly perceived. Before the advent of antitoxin, the mortality of tetanus ranged from 90 to 95 per cent, and following the use of antitoxin by means other than intraspinal, this death rate was reduced at least 20 per

cent. Although in a few isolated series of cases, the rate of recovery has been as low as 12.5 per cent under subarachnoid treatment, one may confidently expect recovery in from 45 to 50 per cent, provided the treatment is instituted early enough and the antitoxin given in sufficient dosage and at proper intervals.

Magnesium Sulphate in the Treatment of Tetanus.—The agonies of tetanus and the fatal outcome in the majority of cases are due, exclusively, to the clonic muscular phenomena. It seems feasible to assume, therefore, that could these exhausting convulsions be controlled, while the patient generated an autogenous vaccine, a larger number would recover. Thus very properly, the administration to the point of tolerance, and within the limits of safety, of motor and sensory depressants of the cord, is indicated. In 1896, this idea was elaborated further by Murphy, who reported good results from the subdural injection of morphin-eucain-salt solution. Uncertainty as to its action, however, prevented this plan of treatment from gaining popular favor and it was abandoned. In 1898, Meltzer noted, during a series of experiments, that the intracerebral injection of a few drops of a 5 per cent magnesium sulphate solution was followed almost immediately by a stuporous condition in which the animal remained for several hours. He noted further that the application of a 25 per cent solution of this drug to isolated nerve fibers produced complete blocking of both sensory and motor impulses without antecedent irritation. After many more experiments and elaborate studies into the nature and character of the magnesium salts, Meltzer demonstrated beyond a doubt that the dominant action of these salts on the living body, no matter how administered, consists in depression or inhibition. In all probability the salts act upon the synaptic membrane, a term used by Sherrington to denote the junction between sensory and motor neurons within the gray matter of the cord and further extended to include that between the end plate and muscle fiber in the muscle. The magnesium salt contained in the lymph or in the cerebrospinal fluid bathing these synaptic membranes, enters easily into these spaces between the neurons and interrupts the passage of nerve impulses from one neuron to another. It may be noted that the synaptic membranes between the neurons offer less resistance to the entrance of magnesium sulphate solution than do the more solid membranes between the motor nerve endings and the muscle. Thus may be explained the mode of the therapeutic action of the magnesium salts in tetanus.

While its action is mainly symptomatic, relieving the convulsions, and if this were its only favorable effect it would be of inestimable value, it is yet quite possible that the presence of the magnesium salts within the synaptic membranes may also prevent the passage of toxin from one neuron to another and thence to the corresponding nerve cells in the spinal cord.

Magnesium sulphate, chemically pure, should be administered intraspinally in a 25 per cent solution, 1 c.c. of the solution to be given for

each 20 pounds of body weight, and the injection should be administered under light general anesthesia. Usually, the relief manifests itself a short time after injection and leads, as a rule, to complete relaxation, lasting from twenty-four to thirty-six hours. During this period the patient is relaxed, partakes of food and may fall into a deep sleep. Sooner or later, however, the convulsions recur and call for a repetition of the injection. This should be given before the clonicity attains its original intensity, before the effects of the previous injection have entirely subsided. The second dose should be slightly smaller than the first, about 0.8 c.c. per 20 pounds of body weight. Subsequent injections must be adapted to the condition of the patient; it is not necessary, however, to attain complete relaxation.

It should be borne in mind that the treatment of tetanus by magnesium is in no sense a substitute for serum therapy and is not free from dangers, the most serious of which is respiratory embarrassment or failure. Mention should be made in this connection of a transitory glycosuria and hyperglycemia, and of its irritant effects upon the renal epithelium. Because of the latter, the treatment is contra-indicated in cases of chronic nephritis. The earliest sign of respiratory embarrassment, such as slow or shallow breathing, demands prompt and specific treatment, including artificial respiration and lumbar puncture. As much cerebrospinal fluid as possible should be withdrawn and the dural sac irrigated with Ringer's solution for which purpose the head and shoulders are elevated to encourage the drainage of fluid from the spinal theca.

In very young children, the initial dose of the salt for intraspinal administration should not exceed 0.5 c.c. of a 25 per cent solution for each 20 pounds of body weight. Since the untoward effect of the salt upon the respiratory center is much more apt to occur in children, the intraspinal administration of magnesium sulphate in very young patients is not advised.

INTRASPINAL TREATMENT OF SYPHILIS OF THE NERVOUS SYSTEM

For many years, even before the advent of salvarsan, the desirability of the direct application of antisyphilitic drugs in specific disease of the central nervous system had been recognized. Our knowledge of the anatomy of the subarachnoid space, of the physiology of the choroid plexus and the cerebrospinal fluid, of the pathology of cerebrospinal syphilis, as well as the evidence that in the treatment of acute infections of the meninges intraspinal therapy was helpful, forecast the benefit to be derived from the direct or intraspinal treatment of syphilis.

In discussing the intraspinal treatment of syphilis of the nervous system it is timely to recall some of the problems which present themselves

TABLE II.—SPINAL FLUID FINDINGS IN EARLY SECONDARY SYPHILIS (FORDYCE)

CASE	DATE I	DATE II	SYMPTOMS	SERUM WASS.	CEREBROSPINAL FLUID CELLS	GLOB.	WASS.	LANGE	REMARKS
M. B.	1/1916	3/15/16	Sluggish pupils	++++	6	±	—	Luetic curve.	Very marked maculo-pap. rash.
J. B.	10/15/15	10/1915	Dizziness; exag. reflexes.	++++	27	—	—	" "	
D. B.	10/1915	1/1916	Dilated fixed pupil.	++++	7	+	—	" "	Grouped papulo-squam. rash.
M. B.	11/1915	11/15/15	None	++++	2	+	—	Negative.	
P. M.	10/1915	2/1916	"	++++	6	—	—	"	
J. F.	9/10/15	1/15/16	Pupils sluggish.	++++	11	—	—	"	Papulo-pustular rash.
S. G.	12/1915	1/1916	Iritis.	++++	1	—	—	"	
E. G.	12/1915	4/6/16	Right disc hazy.	++++	6	—	—	"	
M. M.	12/1915	1/1916	Impaired hearing.	++++	12	—	—	"	
G. M.	1/1916	2/1916	Irreg. fixed pupils.	++++	31	+	—	Luetic curve.	Generalized papular rash.
C. N.	1/1916	3/1916	None.	++++	4	—	—	Negative.	3 Chancres.
J. P.	3/1916	4/10/16	"	++++	5	—	—	"	
H. R.	12/3/15	1/1916	Iritis.	++++	2	—	—	"	
T. R.	?	9/15/15	Headache; exag. knee jerks; fixed pupils; convulsions.	++++	34	++	4+0.2	Paretic curve.	Mucous patches; II rash 9/15/15.
J. V.	12/1915	1/29/16	Reflexes exag. Choroiditis, Papilo-edema left disc.	++++	260	+++	4+0.4	Luetic curve.	
J. D.	12/1915	2/1916	Fundi congested; right disc hazy.	++++	0	—	—	" "	
J. W.	12/1915	1/1916	Pains temporal region.	++++	0	—	—	Negative	
M. R.	1/1916	3/15/16	Headaches; reflexes sluggish.	++++	3	—	—	"	
E. M.	6/1915	8/1915	None.	++	1	±	—	"	
A. L.	10/1915	1/1916	Beginning papillitis; exag. reflexes.	++++	2	—	—	"	
A. R.	9/1915	?	Tinnitus; dizziness; right disc obliterated; left cloudy.	++++	9	++++	4+0.8	Luetic curve.	Symmetrical, ulcerating lesions arms 2 mos. duration. Malignant precocious syphilis.

in the various stages of the disease. While all types are due to the activity of the *Spirochaeta pallida,* the dosage and method of administration are largely determined by a consideration of the localization of the lesion, whether in the cortex, cord, meninges or blood vessels, by the difference in the nature of the response of the various tissues, and by the stage of the disease.

That slight pathological alterations in the cerebrospinal fluid during the secondary period occur with surprising frequency is shown by the observations of many clinicians. Thus, Ravaut has found an abnormal spinal fluid in 67 per cent of his cases; Dreyfus in 80 per cent; Robertson and Klaudner in 70 per cent; Gennerich in 90 per cent; Mattauschek in 80 per cent; Nonne and Mantous in 40 per cent; Wile and Stokes in from 60 to 70 per cent, and the latter believe that in every case of secondary syphilis there is more or less involvement of the nervous system. This does not necessarily mean that there has been a deep involvement of the nervous tissues, but supports the conception that at this early period there is practically a universal distribution of the virus; that there is a reaction on the meninges similar to that on the skin and mucous membranes which usually responds quite readily to treatment.

Although in the second and third year of the disease, alterations in the fluid are more striking, still even in the early stage there may be an extensive meningitis with such profound functional disturbances as to call for heroic treatment. A symptomatic cure in this stage is, however, more complete than is usually attained with the late lesions of the same extent, because in the early stage the lesions are usually meningeal, are exudative and not ordinarily attended by actual destruction of the nervous elements. That the so-called parasyphilitic lesions of the nervous system are the result of the direct invasion of the tissues by the *Spirochaeta pallida* has been shown beyond doubt, and these findings have resulted in a new classification of the late nervous lesions into (1) the interstitial types, which include lesions previously classified under cerebrospinal syphilis, meningitis and gummata, (2) the parenchymatous types, which include tabes and paresis, and (3) a type in which the lesion is essentially vascular. The secondary nervous disturbances are similar to the changes seen in cerebral arteriosclerosis; these are the cases of pure endarteritis syphilitica in which the cerebrospinal fluid shows slight, if any, alterations and the improvement under treatment depends not on the absorption of the syphilitic exudate in the meninges or nervous tissues, but on the extent to which the endarteritis can be favorably influenced.

While the intraspinal treatment of nervous syphilis may be used to advantage in all forms of the disease, it is in the treatment of the parenchymatous varieties that it has found its greatest field of usefulness. This is readily patent when one recalls the anatomical differences in the two types of lesions. While the interstitial type is in large measure amen-

able to antisyphilitic remedies conveyed through the blood, it is readily seen that these methods will fail absolutely to reach the organisms invading the nervous elements of brain and cord. To reach these the agent must gain access to the cerebrospinal fluid. Even after saturation of the blood by antisyphilitic agents, only the very slightest trace can be recovered from the cerebrospinal fluid.

With the introduction of salvarsan and neosalvarsan, the hope was entertained that these therapeutic agents might be safely injected into the spinal theca. This was attempted by Weichselmann, Marinesco, Ravaut and others with almost uniformly disastrous results. In the milder cases, the reaction consisted of various degrees of urinary retention and incontinence, sphincter paralysis, paresthesias and numbness of the buttocks and legs, ataxia in the legs, girdle pains and, occasionally, trophic ulcers. In the more severe cases, there was complete paraplegia with bladder involvement and death from an ascending infection of the urinary tract. Because of these *sequelae,* the direct intraspinal injection of neosalvarsan should be given with extreme caution, if at all, and the dose should never exceed 0.5 mg. A somewhat similar method for the direct application of neosalvarsan was later carried out by Marinesco and Minea, who used the inactivated serum of the patient as a menstruum to which they added from 6 to 12 mg. of the drug. Two out of the nineteen patients treated by them developed severe bladder disturbances. It did show, however, that at least neosalvarsan could be much more safely administered in serum than in saline solution.

Because of these unfortunate experiences, the problem resolved itself into the search for some substance which could be repeatedly injected without injury to the brain and cord. During these studies of the effect of salvarsan and neosalvarsan, Plaut showed that the serum of patients who had received salvarsan intravenously exerted a definite antisyphilitic effect, whereas, normal serum had no such activity, and the serum of patients treated with mercury and iodids had very little. It was then shown that the serum of patients, if taken within six hours after the salvarsan was injected, inhibited the growth of the *Treponema pallidum,* but if taken before the salvarsan was administered, or from six to twenty-four hours afterwards, there was no such inhibition. Further experimental studies on the spirocheticidal activity of salvarsanized serum, especially by Swift and Ellis, showed that heating the serum at 56° C. for half an hour markedly increased its activity. This was due in part to the destruction of some inhibiting substance in the serum. The subarachnoid introduction of this serum prepared after the method of Swift and Ellis has been extensively used with varying but, in many instances, encouraging results.

The Swift-Ellis Treatment.—From 0.6 to 0.9 gm. of salvarsan or neosalvarsan are injected intravenously. One hour later, 40 c.c. of blood

is withdrawn directly into sterile centrifuge tubes and allowed to coagulate, after which it may be centrifugalized. The following day 12 c.c. of serum are pipetted off and diluted with 18 c.c. of sterile normal saline solution. This 40 per cent serum is then heated at 56° C. for one-half hour, after which it is ready for intraspinal injection. Through lumbar puncture sufficient cerebrospinal fluid is withdrawn to reduce the spinal pressure to 2 or 3 mm. of mercury and the serum immediately introduced, preferably by the gravity method, as already described, using the barrel of a 20 c.c. Luer syringe as a container connected with the spinal needle by 40 cm. of rubber tubing. At times, it may be necessary to insert the plunger to inject the last 5 c.c. of fluid. In any event, the serum should be introduced very slowly. The patient should be kept in bed for twenty-four hours and the foot of the bed should be elevated for part of this time in order to encourage the more rapid diffusion of the serum through the lighter cerebrospinal fluid.

Certain objections have been raised and many attacks made upon the *rationale* of the subarachnoid injection of serum salvarsanized *in vivo*. Thus, it has been stated that intravenous methods yield equally good results, that the difficulty in the technic, the pain from intraspinal injections and the unfortunate results which follow the intraspinal injections of neosalvarsan, make all intraspinal treatment undesirable, that the cerebrospinal fluid sometimes contains arsenic after intravenous injections of salvarsan, and that the blood serum withdrawn one hour after intravenous injection of salvarsan does not contain sufficient arsenic to render it of any value for intraspinal injection. Sachs, Strauss and Kaliski show that up to forty-five minutes after the intravenous injection of 0.6 gm. salvarsan, only 0.00004 to 0.0001 gm. metallic arsenic is detected in 20 c.c. of whole blood, and after forty-five minutes practically no free arsenic is recovered.

While it is true that intravenous injections of salvarsan are of great benefit in the treatment of syphilis of the central nervous system, and in many instances effect a symptomatic cure or the arrest of degeneration and the change to normal of the cerebrospinal fluid, still in other cases the conditions remain stationary and yield only to intraspinal therapy.

Although the technic of intraspinal injection is more difficult than that of intravenous injection, this difficulty is not insurmountable and in many instances the additional effort is justified. The pains following injections of human serum are transitory and only occasionally are they severe. On the other hand, the *sequelae* of intraspinal injections of neosalvarsan are frequent enough to be taken into consideration when weighing the relative merits of the intraspinal and intravenous methods of treatment.

Numerous workers have shown the relative or absolute impermeability of the choroid plexus for most inorganic substances, and all are agreed

that but few drugs, which can be demonstrated in the blood after administration by mouth, subcutaneously or intravenously, can be demonstrated in the cerebrospinal fluid. Almost uniformly negative results have been obtained in the search for arsenic in the cerebrospinal fluid after intravenous administration of salvarsan or neosalvarsan, and when present it has been in amounts too small to estimate by the most careful technic. The low arsenic content of the serum has been the chief point of attack by those who have objected to intraspinal treatment. It may be noted in passing that the question is not alone a chemical one but also biologic in nature. Numerous and repeated tests on the serum have shown that arsenic is present in the form of salvarsan. Swift has made very careful tests by the Vinograd method in fifteen patients with twenty-five intravenous injections of 0.5 gm. salvarsan each. The blood was withdrawn after one hour and the serum separated and tested for arsenic content. The results are shown in the accompanying table.

Arsenic Content of Serum in Terms of Salvarsan

Number of sera	Salvarsan per c. c.
	mg.
1	0.05
1	0.04
3	0.03
2	0.025
4	0.02
5	0.01
4	0.006
2	0.005
3	0.004
Total 25	Average, 0.016

While some clinicians are convinced of the value of the Swift-Ellis method, it is reasonable to assume that, as in the employment of other antisyphilitic medications, the maximum efficacy would be more readily attained if we were able to increase or decrease the strength of the agent. Mention has already been made of the experiences of Marinesco and Minea, by whom subarachnoid injections were made with neosalvarsan incorporated in the inactivated serum of the patient. While this method seemed less dangerous than when saline solution was used as the menstruum, it left much to be desired. In 1914 Ogilvie devised his *in vitro* method of preparing salvarsanized serum for subarachnoid administration, and this method bids fair to displace the older Swift-Ellis technic.

Ogilvie Method.—About 50 c.c. of blood is withdrawn into a centrifuge tube and the latter is immediately placed in a large centrifuge and the fibrin and cellular elements thrown down. It requires a speed of about 3,000 revolutions for fifteen minutes to produce a perfectly clear serum.

It is rarely necessary to centrifugalize more than once if the blood be freshly drawn, but the process should be repeated if the serum be not absolutely free from cells and fibrin. To 15 c.c. of the serum is then added the amount of salvarsan to be given. This is done by mixing the salvarsan as for intravenous treatment, using freshly distilled and boiled water and bringing the total quantity up so that each 40 c.c. of the solution will contain 0.1 gm. of the drug. Each cubic centimeter of this solution will then contain 2.5 mg. of salvarsan. With a 1 c.c. pipette, graduated in tenths, the desired amount can be readily measured from 2.5 mg. upwards. In using sodium hydroxid, it is of the greatest importance to use only the exact amount required to alkalinize the solution faintly. When this has been once determined by testing with litmus paper, the sodium hydroxid should always be added quickly and not drop by drop. It is also very important that the temperature of the salvarsan solution and serum be the same when the two are mixed. The serum is then gently agitated in order that the two be thoroughly mixed, and this is placed in a thermostat at 37° C. for forty-five minutes. From this it is placed in a thermostat at 56° C. for thirty minutes. It is now ready to give intraspinally and it should be used as soon after preparation as possible. Under no circumstances should serum be used which is more than three hours old.

The method of introduction of this serum differs in no way from that of the subarachnoid administration of other sera. It is given preferably by the gravity method. As regards dosage, as high as 4 mg. of salvarsan has been given at a treatment without ill effects. Despite the fact that in some instances the larger dose has been tolerated, for various reasons the dose should not exceed 1 mg. This amount of salvarsan is well borne and experience has shown that improvement is even more marked than when larger doses are used. Besides, while nothing is gained by using the larger quantities of the drug, the possibility of injury to the nerve tissue is reduced to a minimum when the dose is kept within the above mentioned limits.

For repeated injections, from 0.25 to 0.5 mg. is the safest and most effectual dose to employ. In the intraspinal use of salvarsanized serum, an indefinite number of injections are required. These may be given at from one- to three-week intervals, depending upon the condition of the patient. Theoretically, the treatment should be continued until the Wassermann reaction in the cerebrospinal fluid becomes negative, the cells reach normal proportions and the globulins show no increase. Practically it may be impossible to secure these results. In many instances, the Wassermann reaction is the first to disappear.

While there have been recorded many and various discomforts following the intraspinal injection of salvarsanized serum, *pain* is the most conspicuous of all. This varies in intensity from slight twinges to that of the severe racking type, which can be controlled only by morphia. In a total of 355

injections recorded by Draper, there were 104 reactions of all sorts (30 per cent); of these, 78 (22 per cent) were painful. If the number of patients be considered rather than the number of injections, about 80 per cent will have pain, not at every injection necessarily, but at some time during the course of the treatment. The following list contains the variety and approximate percentage of the symptoms commonly observed:

Pain in the legs	13.8 per cent.
Headache	5.3 " "
Odd sensations in legs	1.4 " "
Numbness in legs and perineum	1.4 " "
Nausea	.8 " "
Vomiting	1.9 " "
Psychic exaltation	.3 " "
Coma	.3 " "
Vesical paresis	.3 " "
Paraplegia	.3 " "
Increased ataxia	.5 " "
Sensation in head	.3 " "
Weakness	.3 " "

The pain may occur at various periods in the whole precedure and in various parts of the body. A rather common type of pain reaction is that in which the pain begins during the inflow of the serum. It is occasionally felt in the sciatic distribution, sometimes, at the point of punctures, lasts but a minute or so and passes off as quickly as it appeared. Pain may also appear a few minutes after the withdrawal of the needle and at this time is often severe, usually felt in the thighs, or in the calves of the legs and feet. It may last anywhere from a few minutes to an hour or so, although it may recur with more or less severity from time to time during the night following the treatment. Another type of pain is that which occurs in cases of tabetic crises and consists in an exacerbation of the paroxysms, continuing several days after the treatment. A fourth type of pain is more serious and is a part of the general reaction of considerable severity. There may be no pain at the time of injection or immediately following it for several hours. Then the patient begins to feel chilly and uncomfortable and there is general malaise and headache. Soon there is a moderate febrile reaction, a violent headache and intense pain in the back and legs. Objectively the patient presents the picture of meningism; the neck is stiff and Kernig's sign is present.

In most cases the pain is so transient and slight that no treatment is needed, but when the pains are severe, deep muscular massage of the thighs and calves of the legs will often relieve at once. The pains of the tabetic crises are best controlled by heat to the lumbar spine and over the painful area and by the administration of phenacetin, caffein and codein, occasionally morphin. In extremely rare instances, lumbar puncture may be necessary to relieve the pain.

The term "odd sensations in the legs" refers to sensations which do not amount to pain but are sufficiently uncomfortable to attract the subject's attention. Numbness in the legs and perineum is a well recognized sequel to the direct introduction of too much salvarsan or neosalvarsan. It is usually associated with retention of urine, may persist for a long time and in a very few cases seems to be permanent.

It is quite reasonable to suppose that *syphilitic antibodies* are also present in the serum, although as yet they have not been demonstrated. It is a significant fact that the serum of salvarsanized patients has had a curative effect when injected into infants with congenital syphilis, and also into subjects with acquired syphilis. This curative effect is supposed to be due to an increase in antibodies excited by the salvarsan. It may be that the transient aseptic irritation which follows the intraspinal injection of serum may be of benefit.

Intraspinal Injection of Mercurialized Serum.—It has been suggested that better results might be secured in the subarachnoid treatment of syphilis if a larger quantity of some specific drug were introduced into the subarachnoid space. As we have already seen, the direct introduction of salvarsan or neosalvarsan in any appreciable quantities cannot be done without serious risks to the patient. Mercury, the remaining antisyphilitic remedy, has been tried by Horsley, Rivaut and others, both the chlorid and cyanid salts, with dangerous and discouraging results. They are scarcely less toxic, in appreciable doses, than the more unstable arsenical preparations. If mercury is to be used at all, it is evident that a preparation must be obtained which is therapeutically active, and at the same time possesses comparatively low toxicity and local irritative action. When an inorganic salt of mercury comes in contact with protein matter a coagulative process occurs in which the insoluble albuminate of mercury is formed. The occurrence of this reaction led Byrnes to believe that it might account for some of the unpleasant symptoms following the direct introduction of inorganic salts of mercury into the spinal theca. If mercury exhibits this affinity for the protein molecule, it would seem advisable to make use of a preparation in which this affinity is already satisfied. Although its toxicity may be no less than that of the inorganic salts, it was thought that the albuminate might be less irritating, and especially so if administered in a serum menstruum. Since the commercial albuminate is difficult to obtain, unstable and insoluble, it was decided that more satisfactory results might be obtained by adding a mercurial salt directly to human serum.

The precipitated albumin which is at first formed is readily soluble in an excess of albumin, so that on further addition of serum a perfectly clear solution is obtained. By fractional precipitation Byrnes determined that approximately 0.022 gm. of mercuric chlorid, in solution, must be added to 2 c.c. of serum before precipitation is complete, and that it

was necessary to add 4 c.c. more of serum in order to dissolve this precipitate completely. In other words, 6 c.c. will hold in solution 0.022 gm. of mercuric chlorid converted into the albuminate.

Sufficient blood, about 50 c.c., is withdrawn to yield 12 to 15 c.c. of serum. After the blood has coagulated, the serum is pipetted off under aseptic precautions, and, if necessary, centrifugalized for twenty minutes. To the 12 c.c. of the centrifugalized specimen is added 1 c.c. of a solution of mercuric chlorid in freshly distilled water, so that each cubic centimeter contains 0.0013 gm. of mercuric chlorid. To the serum thus prepared is added a sufficient quantity of normal salt solution to make a total volume of 30 c.c. The serum is headed at 56° C. for half an hour and administered exactly as is salvarsanized serum.

The after-treatment does not differ in any respect from the care of the patient following the subarachnoid injection of salvarsanized serum. The reaction following the administration of mercurialized serum is usually mild. There is some pain in the legs for from six to twelve hours, slight nausea, rarely vomiting, and a moderate rise in temperature. All of these symptoms generally subside within thirty-six hours. Sphincter disturbances have not been observed, nor has there been any evidence of renal disturbances or other untoward symptoms.

By many, mercurialized serum was thought to be as efficacious as salvarsanized serum, if not more so, but the later clinical results of its application do not warrant its endorsement. Since preliminary medication is not required, the blood may be obtained at any time, and because of the greater stability of the mercurialized serum, it may be prepared at leisure and kept in sealed flasks until it is convenient to administer it.

Recently the plan to furnish a stock mercurialized horse serum has been proposed for the purpose of providing the physician a convenient preparation for intraspinal injection. Such sera are now on the market, but their undesirability is obvious. It has been shown that even an homologous serum can be rendered dangerous as a foreign protein by the addition of salvarsan, and on this basis some of the rare and severe reactions following the intraspinal injection of salvarsanized human serum have been explained as anaphylactic in nature. Furthermore, Longcope has shown that repeated injection of foreign protein, which produces successive sublethal anaphylactic shocks, causes definite tissue changes in the heart and kidneys.

Results.—In judging the results of intraspinal treatment of syphilis, we must consider improvement both in function and in the laboratory findings. It is the degenerative types, tabes and paresis, that have proved so intractable to treatment. A neuron once degenerated is hopelessly destroyed and, unfortunately, many cases come to the neurologist or surgeon only after the central nervous elements have become seriously involved. Under such circumstances, the most that can accrue from treat-

TABLE III.—SEROLOGICAL RESULTS IN PARESIS BEFORE AND AFTER TREATMENT (FORDYCE).

		Before Treatment					Treatment			After Treatment					
		Cerebrospinal Fluid				Blood				Cerebrospinal Fluid				Blood	
Case.	Date.	Cells.	Glob.	Wass.	Lange	Wass.	Salv. I. V.	Salv. I. S.	Hg. Injts.	Date	Cells	Glob.	Wass.	Lange	Wass.
H. H.	12/12/13	26	+	4+ 0.6	5555554100	++++	30	34	7	1/12/16	2	++++	4+ 0.4	5555555430	±
E. R.	8/23/14	180	++++	4+ 0.05	5544443200	++++	31	41	38	2/16/16	6	++	4+ 0.2	5555542000	+++
E. N.	11/11/14	16	++++	4+ 0.2	5555543100	++++	14	23	0	4/ 5/16	13	+	4+ 0.4	5555430000	++++
H. M.	5/11/14	30	++++	4+ 0.05	5555543100	++++	12	20	0	6/ 1/15	8	++++	4+ 0.4	5555543100	++++
G. J.	3/29/15	75	++++	4+ 0.4	5555543200	++++	10	15	29	4/21/16	12	++	4+ 0.4	5555553000	Negative
W. A.	2/20/15	290	++++	4+ 0.05	5555542100	++++	23	25	22	4/26/16	7	++++	4+ 0.4	2223332000	++++
W R.	6/28/15	100	++++	4+ 0.05	5555542000	++++	7	5	10	4/29/16	2	++	4+ 0.4	5555432000	++++
L. F.	11/27/15	75	++++	4+ 0.1	5555555543	++++	5	18	0	4/19/16	10	++++	4+ 0.1	5555555400	++++
H. W.	5/19/15	3	++++	4+ 0.1	5544442100	++++	11	20	11	12/22/15	0	±	2+ 1.0	1134330000	Negative
F. P.	10/ 5/15	60	++++	4+ 0.2	5555555200	++++	10	16	2	3/29/16	6	++++	4+ 0.2	5555554300	++++
B. A.	12/18/15	45	+++	4+ 0.1	5555542000	++++	6	9	16	4/19/16	7	++	4+ 0.4	5555430000	++++
W. L.	3/24/16	110	++	4+ 0.1	5555554400	++++	4	3	6	4/12/16	24	++++	4+ 0.1	5555554400	++++
M. H.	3/ 9/16	35	+++	4+ 0.6	5555543000	++++	4	4	3	4/19/16	10	+++	4+ 0.4	5555543000	++++
F. H.	1/22/16	40	+++	4+ 0.2	5555555520	++++	4	4	0	4/29/16	11	++++	4+ 0.1	5555555300	++++
T. R.	2/11/16	34	++	4+ 0.2	5555542200	++++	13	0	50	4/26/16	3	++	4+ 0.6	5555530000	++++

ment is an arrest of the degenerative process and the consequent protection of the remaining healthy neurons. In the interstitial forms, on the other hand, absorption of the exudate will often result in remarkable functional cures. Certainly we see more functional recoveries and a more rapid return to normal of the cerebrospinal fluid in the interstitial forms than in tabes and paresis. (See Table III.)

While tabes and paresis have been grouped together, there are many striking differences in the two diseases as regards response to treatment. In tabes, treatment frequently results in the arrest of degeneration and in marked diminution or disappearance of the pathological elements in the cerebrospinal fluid, while it is most difficult to obtain a favorable response in the fluid of paretics. This may be due to a difference in the accessibility of the two lesions.

In an analysis of the results in 34 cases of tabes in which observations have extended over at least a year and a half, and in some, nearly five years, Swift has summed up his experiences with the Swift-Ellis method of treatment. Three of these cases received intraspinal treatment alone, the remaining, intravenous and intraspinal injections with the following results: 25, or 73 per cent, had negative Wassermann reactions in 1 c.c. of cerebrospinal fluid. Of these 25, 14, or 41 per cent of the total, had negative reactions in 2 c.c. of fluid, an amount double the maximum recommended by Hauptmann and Hoessli. In 8 cases, the reaction was negative in 1 c.c. but positive in 2 c.c. of the fluid.

The following records (Table IV) show the serological results in sixteen cases of nervous syphilis other than paresis (Fordyce).

On the whole, the experience with paresis is discouraging as compared with the more positive results obtained in tabes. We may, however, anticipate that under proper intraspinal treatment with salvarsanized serum, in from 70 to 75 per cent of tabetics, the spinal fluid will become negative, chemically and biologically, and that, clinically, a smaller number will be strikingly improved as to gait, lightning pains, bladder symptoms and general physique. The most that can be said of paresis is that in some cases the process appears to have been arrested.

Perhaps a better way of judging the results of intraspinal treatment is by its effect upon working capacity, and in the accompanying table are shown the results, in terms of working capacity, of the intraspinal treatment in 38 cases of cerebrospinal syphilis:

Condition	Before treatment	After treatment
Useless	26	6
Working part time or suffering	11	8
Working full time	1	22 (Draper)

TABLE IV.—SEROLOGICAL RESULTS IN CASES OF NERVOUS SYPHILIS OTHER THAN PARESIS (FORDYCE).

		Before Treatment							After Treatment			
		Blood	Cerebrospinal Fluid			Amount of Treatment			Blood	Cerebrospinal Fluid		
Case	Diagnosis	Wass.	Cells	Glob.	Wass.	Solv. I.V.	Solv. I. S.	Hg Injts.	Wass.	Cells.	Glob.	Wass.
W. G.	Tabes	4+	34	2+	4+ 0.2	19	1	17	+	3	+	Neg.
T. C.	"	Neg.	9	4+	2+ 1.0	11	6	12	Neg.	3	Neg.	"
I. G.	"	4+	160	4+	4+ 0.4	6	5	12	"	0	+	"
S. G.	"	4+	73	4+	4+ 0.4	5	6	8	"	0	Neg.	"
L. F.	"	4+	128	4+	4+ 0.2	10	7	12	4+	0	+	"
J. H.	"	4+	150	4+	4+ 0.4	11	9	20	4+	0	±	"
W. R.	"	Neg.	81	4+	4+ 0.4	5	7	0	Neg.	0	±	"
E. M.	"	"	12	2+	1.0	12	0	22	"	6	Neg.	"
G. R.	"	4+	70	4+	4+ 0.4	12	11	12	"	0	"	"
L. C.	Optic atrophy	Neg.	60	4+	4+ 0.2	5	6	0	"	0	+	"
S. G.	"	"	35	4+	4+ 0.6	3	4	0	2+	4	2+	"
H. R.	Cerebrospinal syphilis	4+	46	4+	4+ 0.6	12	0	40	Neg.	0	Neg.	"
H. H.	"	4+	235	4+	4+ 0.6	13	1	20	4+	8	++	"
E. R.	"	4+	90	4+	4+ 0.1	7	7	8	4+	0	+	"
M. G.	"	4+	96	4+	4+ 0.4	4	11	0	4+	0	Neg.	"
L. T.	"	4+	51	3+	4+ 0.2	9	10	26	2+	3	+	"

Recently our attention has been directed to some experimental and clinical work in which the therapeutic agent has been brought in close contact with the diseased process by ventricular and subarachnoid injections; though in too early a stage to warrant a final decision, *a priori,* this method would seem to promise more for paresis than the more indirect method of intraspinal injection.

Our greatest hope in the cure of syphilis of the nervous system lies in the adoption of appropriate methods at its inception. Failing this, too great stress cannot be laid upon the early recognition of signs or symptoms which point to involvement of the cerebrospinal axis. The syphilographer and dermatologist, by contact with cases of secondary syphilis, are in a position to discover the earliest clinical signs of involvement, such as irregularity of the pupils and irresponsiveness to light, exaggeration of the knee jerks, headache, auditory and ocular defects, or oculomotor paralyses. These are all positive indications for lumbar puncture. If dermatologists and genito-urinary surgeons were familiar with the earlier manifestations of the disease, they would uncover many cases of nervous syphilis against which a therapeutic attack could be made and the patient rendered secure from future degenerative changes.

The treatment in the early active stage must be intensive and systematic and should comprise a combination of salvarsan and mercury, for we have learned that salvarsan alone is apt to be followed by neurorecurrences. It has been shown that, in patients inadequately treated, a pleocytosis, with marked increase of globulin and a strongly positive Wassermann reaction, may be present without outward evidence of the disease, the latter remaining latent for years, when signs of tabes or paresis make their appearance. By this time the nerve tissue may be irreparably damaged. It is, therefore, incumbent upon the syphilographer to treat the fresh infection energetically, and wherever practicable to examine the spinal fluid at the completion of the treatment or, in the absence of physical signs, after a provocative injection of salvarsan, which should be given one year after the Wassermann reaction has been continuously negative.

In patients with a negative blood and a positive fluid reaction, a provocative injection of salvarsan should be administered and the Wassermann reaction taken at stated intervals. Though the blood reaction continue negative, subarachnoid treatments should be begun at once. When both blood and fluid reactions are positive, two or more injections of mercury should precede the intravenous administration of salvarsan, and after two or three doses of the latter, the intraspinal injections should be instituted and supplemented by the intravenous. In paresis my usual practice is to begin with the intraspinal injections after the first intravenous treatment. The intervals between doses, and this applies to both routes of introduction, are regulated by the reaction produced in the patient. Where subdural injections are well borne, they may be given in series of

four to six, one to two weeks apart, with a rest period of four to six weeks, and then another course. Frequently, tabetics are met in whom intraspinal medication cannot be repeated oftener than once a month.

While in the larger percentage of cases there is little risk attending either intravenous or intraspinal treatment in disease of the nervous system, it is not altogether a harmless procedure, and it cannot be emphasized either too strongly or too frequently that every precaution be carefully carried out in regard to the preparation and size of the dose and to the necessity for rest in bed after the injection. Whether in the subarachnoid injections the untoward effects mentioned are due to the irritating action of the arsenic, or to a change in pressure acting on the diseased vascular walls, cannot be positively asserted.

The results of the treatment may be grouped according to their effect on the biological findings and the clinical status of the patient. Cure, amelioration or failure is dependent upon the extent and type of the morbid process,—that is to say, whether an active meningeal inflammation be present or degeneration of the essential nerve structures. While the same physical signs may be produced by both processes, their prognosis is quite different. Where the symptoms are due to an active inflammation with strongly positive fluid, the outlook is very encouraging. Where, however, the underlying process is one of degeneration with atrophy and sclerosis, with negative or weakly positive fluid findings, the prognosis is grave.

Of the laboratory findings the pleocytosis is most susceptible to therapy and usually disappears after a few injections; in many cases with intravenous treatment alone. The Wassermann reaction and the globulin content are more refractory, the latter persisting even after the Wassermann reaction has become negative. The influence of treatment on the Wassermann reaction in the fluid depends upon the character of the lesion.

The clinical achievements may be summarized as follows: in active progressive tabes the lancinating pains are ameliorated or disappear entirely; the gastric and rectal crises are usually controlled, or regress, and the ataxia is markedly decreased, and in some cases disappears; disturbances of sensation partially or completely clear up; sphincter control and sexual power improve or return to normal; the patients feel better, put on weight, and are able to resume their occupation. No return of absent reflexes has been noted.

In those cases which do well the rapid and satisfactory improvement may lead to a premature cessation of treatment. For the elaborateness of the procedure arouses an impulse on the part both of patient and physician to curtail the number of treatments. But with our present knowledge of the significance of serological reactions, so long as the spinal fluid or blood gives a positive Wassermann test, the case must be looked

upon as one potentially capable of relapse. Consequently, no matter how well the patient feels and seems to be, treatment must be continued unremittingly until the laboratory tests are persistently negative.

In presenting the various methods of intraspinal therapy of syphilis, I have purposely refrained from making any radical or extravagant claims. The subject is still *sub judice* but the results obtained, while not as uniform or striking as was originally anticipated, at least justify its continued application in selected cases. At all events, until additional clinical data have been accumulated for review, the intraspinal treatment should not be altogether abandoned.

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CHAPTER XIV

SPINAL ANESTHESIA

INTRADURAL ANESTHESIA

In 1898 the first operation under spinal anesthesia was performed by Bier. A resection of the ankle joint for tuberculosis was planned, and since in previous operations the patient had always borne the anesthesia badly and dreaded another experience, Bier determined to try the effects of cocainizing the cord as a substitute for general anesthesia. He injected 3 c.c. of 0.5 per cent solution of cocain (in all 0.015 gm.) and completed the operation without any pain whatsoever. Two hours afterward the patient complained of pain in the leg and sacrum, which soon disappeared, but the vomiting and severe headache that followed the injection lasted until the next day. Within a fortnight five additional operations were performed under spinal anesthesia, all successfully. As a matter of historical interest I make mention of the personal experiences of Bier and Hildebrand, who, in the interest of safety and science, determined to test upon themselves the effects of an intraspinal cocain injection, a praiseworthy performance. Bier was given 0.005 gm. cocain, but, as the needle did not fit the syringe, much of the fluid escaped and the observation was fruitless. Hildebrand was given an intraspinal injection of 0.5 c.c. of a one per cent solution of cocain (0.005 gm.) and his description of the consecutive phenomena is interesting, coming as it does from a trained and competent observer. Immediately after injection there was a sense of warmth in both legs and seven minutes later the point of a needle on the thigh and tickling upon the sole of the foot could scarcely be felt. In eight minutes, only the pressure of a small incision in the skin of the thigh was felt and heavy stroking of the thigh with a large blunt needle was not in the least painful. Ten minutes after the injection a large needle was plunged through the overlying tissues down to the femur without pain, and in eleven minutes sensation of pain in the arm was much diminished. Two minutes later the sensation of a lighted cigar close to the leg was that of warmth but not pain, and the application of ether aroused a sensation of cold. By the fifteenth minute tickling of the sole of the foot could not be appreciated as such, but more as the sense of touch, and pricking communicated in the legs the sense of pressure and on the thorax the sense of pain; in twenty minutes pulling out the

hair from the pubic region felt as though the skin were being raised; and in twenty-three minutes a blow upon the shins with a metal hammer was painless. Sensation did not begin to return until forty-five minutes had elapsed; at first it was not very acute, but little by little became normal. In the course of the night Hildebrand had a severe headache and vomited twice. The morning after he felt miserable, but with great effort was able to do some operating and dressings. For three to four days he felt out of sorts, and, while able to continue his activities, he complained of lassitude for several weeks.

In considering the arguments for or against spinal anesthesia, the mortality, the failures, the accidents on the table, the complications and the sequelae are of vital importance. These will be discussed *seriatim.*

Mortality.—Let it be remembered by the reader that the mortality records available are in most instances from the clinics of those who are advocates of spinal anesthesia, who employ it frequently, who have given a great deal of thought and time, as they should, to the refinement of the technic and to the elimination of risks, and who, as a result of this intensive study, are more proficient in its application. In other words, the anesthetic is administered under the most favorable circumstances by a selected group of trained and accomplished surgeons. Under such conditions the results are inevitably better than could be expected in the hands of those who employ spinal anesthesia only exceptionally. Therefore, in the consideration of spinal anesthesia, those who are not staunch advocates of it and do not employ it routinely should discount somewhat the low mortality, the freedom from risks or *sequelae* that make this form of anesthesia appear of greater safety and usefulness than ether or nitrous oxid.

I have selected for presentation and analysis the following groups:

TABLE I

Series	I	Barker and associates	2,354 cases	3	deaths
"	II	Helm	1,419 "	3	"
"	III	Babcock	5,000 "	10	"
"	IV	Sellheim	1,000 "	1	"
"	V	Richards	500 "	3	"
			10,273 cases	20	deaths

Series I.—In this series the three deaths occurred under the following circumstances: the first after an exploratory operation in an extensive carcinoma of the stomach in a decrepit old man; the second followed five hours after a short circuit operation in a middle-aged woman with prolonged obstruction and extreme distention secondary to a carcinoma of the sigmoid; the third patient had an acute intestinal obstruction and after the injection he vomited, flooded the larynx and died of asphyxia. Barker, commenting upon these deaths, states that they occurred at a time when the limitations of spinal anesthesia were far less understood, that

not one of these cases would now be considered a suitable subject and that they probably would have succumbed under any form of anesthesia. With these exceptions, there have been no deaths in 2,354 cases.

Series II.—In the series of 1,419 cases from von Hacker's clinic the operations included some in both the upper and lower abdomen as well as the lower extremities. Three cases died on the table: the first during resection of the bowel in a case of strangulated hernia; the patient (male, *aet.* 62) vomited, suddenly became cyanosed and died; the second death occurred suddenly in a male patient of 62 years during an attempt to reduce a dislocation of the hip; the third patient, *aet.* 44, with symptoms of peritonitis, was operated upon under spinal anesthesia; during the exploration, which revealed a tear in the mesentery and liver perforations, the patient died.

Series III.—Under Babcock and his assistants there were ten deaths on the operating table and one after the operation in 5,000 intradural injections. (1) The first case had gangrene of the leg and thigh following a crush injury, and died of respiratory difficulty fifteen minutes after the injection of alypin. (2) The second case died six hours after an avulsion of the upper extremity; pulseless and shocked at the time, the patient had respiratory failure after a high injection of stovain. (3) A man of 65 years with generalized peritonitis from typhoid perforation died on the operating table after injection of tropacocain. (4) Searching for an intralobular abscess in an infant with miliary tuberculosis, respiratory failure followed a high injection of 0.0015 gm. stovain. (5) A man of 55, with intestinal gangrene and diffuse purulent peritonitis, died on the operating table. (6) A middle-aged patient with an enormous empyema developed cardiac failure after the evacuation of the pus. (7) A middle-aged man died of sudden heart failure after the escape of a large quantity of pus. (8) A young woman of 32 died on the same day after a rib resection and the evacuation of three pints of pus. (9) A woman of 60 apparently drowned by profuse regurgitant vomiting, as the operation, a cholecystectomy, was being completed. (10) A man of 50 died of respiratory failure on the table in the course of an operation upon the gall-bladder. (11) A colored woman died "undoubtedly as a result of circulatory arrest" two days after the operation. Commenting upon these experiences, Babcock writes: "Contrasting our personal experience with ether and spinal anesthesia both have proved to be dangerous, but spinal anesthesia no more than ether."

Series IV.—In the series of 1,000 gynecological operations in the Tübingen Frauenklinik, three-fifths were abdominal and two-fifths vaginal. In these 1,000 cases there was only one death which Sellheim attributed to spinal anesthesia; this was in a cesarean section just before the incision was made. In the entire series the postoperative mortality was 4 per cent, death being due to sepsis, embolism, nephritis and diabetes. Apart from these general statements no details are given.

Series V.—This is a series of 500 cases in which spinal anesthesia was first used by Owen Richards in a native hospital in Cairo. According to Richards, "Death from spinal anesthesia when it occurs seems to occur at once, that is to say, during or at the end of the operation." According to this interpretation of "anesthetic death," there were three cases in his series: (1) a nonagenarian with an enlarged prostate died one-half hour after the operation, which lasted only seventeen minutes; (2) a man of 45 with septic bladder and kidneys died of heart failure at an operation for the closure of a suprapubic fistula; (3) a young man one day after an amputation for a crushed leg developed free hemorrhage; the flaps were opened up under stovain anesthesia and the patient died in seven minutes. Commenting on these cases, the author says of the first case that the operation should not have been undertaken in this way, of the second, had the patient's chest been examined he would not have come to operation, and of the third, the

risk would have been great under any circumstances; the operation should have been done without the aid of any anesthetic.

TABLE II

SUMMARY OF 20 FATALITES IN 10,273 OPERATIONS

No.	OPERATOR	OPERATION	TIME OF CATASTROPHE
1.	Barker	Exploratory operation for gastric carcinoma	On the operating table
2.	"	Lateral anastomosis for intestinal obstruction	Five hours after operation
3.	"	Acute intestinal obstruction	On the operating table
4.	Helm	Resection of bowel for strangulated hernia	" " " "
5.	"	Reduction of dislocation of hip	" " " "
6.	"	Exploratory operation for perforation of bowel	" " " "
7.	Babcock	Amputation for gangrene of the leg	" " " "
8.	"	Avulsion of arm (high injection)	" " " "
9.	"	Operation for typhoid perforation	" " " "
10.	"	" " abscess of lung (high injection)	" " " "
11.	"	" " intestinal gangrene	" " " "
12.	"	Evacuation of pyothorax	" " " "
13.	"	" " "	" " " "
14.	"	Resection of rib for empyema	Day of operation
15.	"	Cholecystectomy	On the operating table
16.	"	"	" " " "
17.	Sellheim	Cesarean section	At beginning of operation
18.	Richards	Prostatectomy	One and one-half hours after operation
19.	"	Suprapubic exploration	On the operating table
20.	"	Hemorrhage following amputation	" " " "

It is difficult to estimate the mortality of spinal anesthesia, so many are the factors that have to be taken into consideration: the condition of the patient, the character of the lesion, the selection of the drug and the dosage. In justice to those who advocate spinal anesthesia, it is necessary to take into account the fact that many of the deaths were in subjects so desperately ill that general narcosis was contra-indicated. The five series of cases, totaling 10,273, were selected as representative of clinics in different countries and of operations for various lesions below the diaphragm, including 1,000 upon the pelvic organs. Stating the facts baldly, the proportion of deaths in this collection of 10,273 cases was 1:513. This ratio is almost identical with that which Chiene estimated in his collection of 12,000 cases with 22 deaths, or 1:570 (in our estimation it should be 1:545). In Strauss' collection of 22,717 cases there were 46 deaths, or 1:498. Eliminating 25 of these deaths in 6,875 cases

where cocain was used, there remain 21 deaths in 15,842 cases where other anesthetics were used. Of these, however, only 12 cases were definitely stated as due to the anesthetic or seemed to have connection with it, which gives a ratio of 1:1,320. Michelsson in reviewing the divergent results of various reports concludes that a fair estimate of the mortality of spinal anesthesia is 1:3,500. As a matter of fact, it is difficult to find a series of cases in which there has not been at least one death in a thousand cases, so that we are disposed to regard Michelsson's percentage as too low. Accepting Michelsson's figures as a fair valuation of the risks incident to spinal analgesia, namely, 1:3,500, for purposes of comparison, the estimated mortality of ether anesthesia should be stated. In his Ether Day Address in 1915, Keen gives the average ether mortality as 1:7,706, qualifying this statement by the fact that in certain clinics the mortality is as high as 1.451, whereas in others there have been over twenty thousand administrations without a death.

Complications.—The complications of spinal anesthesia are those incident to lumbar puncture, to artificial variations in the intraspinal pressure and to the direct physiological action of the drug employed. Of those due to lumbar puncture mention need be made only of motor and sensory, terminal disturbances from impingement of the needle upon caudal roots, of headache and vomiting from disturbance of pressure, of respiratory catastrophes and of meningitis. Of the latter a number of cases have been reported. In the experience of one surgeon (Helm) there were four cases, three of which fortunately recovered.

Considered specifically, as consequent upon the disturbance of pressure and upon the toxic or irritating effect of the drug, should be mentioned headache, nausea, vomiting and vertigo, various effects upon the cord and roots, shock, collapse and respiratory embarrassment. *Headache* is the most distressing subjective symptom and not infrequently is most intense. It may be expected in from fifteen to twenty per cent of one's series and has been attributed to pressure disturbances, in most instances to a decrease rather than an increase in pressure. Helm has noticed headache especially after the rapid withdrawal of fluid and a corresponding fall in blood pressure in patients with a high cerebrospinal pressure. No doubt we are having fewer headaches now than in the earlier days of spinal anesthesia, partly because we are paying more attention to the preparation used, but more particularly because we are giving greater consideration to the proper adjustment of spinal pressure. The pressure should be carefully measured before the injection and at the time of injection so that the normal conditions may, as nearly as possible, be maintained. There is a striking variation in the degree of headache from one of little consequence to one of agonizing character, and it may last from a few hours to a few days after the injection. Sometimes the headache is occipital, sometimes parietal and occasionally a hemicrania. Helm re-

cords headache as a complication in twenty per cent of his 1,419 cases, and, speaking of the late effects, says a number of patients complained of headache from one to six months afterward. The treatment for headache is the restoration of spinal pressure to normal: if pressure be increased, fluid should be withdrawn; if decreased, normal saline solution may be given by proctoclysis or subcutaneously, or an isotonic solution may be injected directly into the canal. To employ these measures intelligently and accurately a properly appointed spinal manometer is essential.

Incidental to these pressure disturbances may be mentioned a group of symptoms, which are due also, I believe, not so much to irritation of the meninges as to the disturbed pressure—namely, *dizziness, nausea, vomiting, muscular rigidity and localized tenderness.* Bier and Barker, however, attributed these to the irritating effect of the alkali, soda, which was used in boiling the instruments, and Barker was of the opinion that the alkali might destroy the effects of stovain; hence the injunction not to add soda to the water in boiling the instruments. At all events, after the soda was eliminated in the Bier clinic stiffness of the neck disappeared. In Babcock's series of over 5,000 cases, 18 per cent complained of nausea and 13 per cent vomited. In one-fourth of these cases the nausea and vomiting were recorded as slight; in three-fourths, presumably, they were intense. Anent the effects of increased pressure and irritation within the cerebrospinal sac, I must not forget to mention the sharp rises in temperature sometimes observed and attributed to irritation of the heat center.

Pulmonary lesions are recognized as complications of ether, although the mode of infection is not clearly understood. The experience of those using spinal anesthesia differs on this particular point. I find Hohmeier and Koenig with their 2,400 cases convinced that the incidence of pulmonary complications, in their experience about 1.7 per cent, is no greater than under general narcosis. Experiences differ as to the effect of spinal anesthesia upon the kidneys. Babcock reports that he was unable to find any albuminuria after spinal anesthesia, although it was frequent after ether; others report albumin and casts in the urine in 60 per cent of cases within a few hours to a few days. However, the changes in the kidney are not of a permanent character and have never been serious enough to be fatal.

The effect of spinal anesthesia upon the *nervous system* has been brought forcibly to our attention by both experimental and clinical evidence. From both these sources it has been established that stovain not only has an irritating effect upon the cord, but seems to have a predilection for the motor ganglion cells in the anterior horns. The experiments of Spiller and Leopold show conclusively the damaging effect of the drug upon the cord and roots of the dog. As to the effect of stovain upon the spinal cord of man, the reader is referred to Spielmeyer's report of the examination of the central nervous system of thirteen patients who died after the

injection of stovain. The changes were extremely variable as to the degree of damage, but they were confined mostly to degeneration of the motor ganglion cells and, as in Spiller's experiments, these changes were observed not only at the level of injection but five centimeters above. There seems to be a direct relationship between small and large doses in Spiller's investigations, as in Spielmeyer's studies, no degenerative changes being observed when the dose did not exceed 0.9 gm. Although there have been observed unquestionable changes in both the roots and the cord in the experimental dog, the physical conditions in man attending spinal anesthesia must be radically different, since evidence of grave complications in man has been wanting, save in rare instances. As Spiller says, "It would be unwarranted to apply these findings (experimental) too strictly to man, as no grave changes have been found as yet in the human spinal cord."

Of the *paralyses* following spinal analgesia those of the oculomotor nerve and the abducens have given rise to considerable discussion. They have been attributed variously to hemorrhage, to increase in cerebrospinal pressure and overstretching of the nerves, but the most plausible theory is that which attributes the palsies to the toxic effect either of the drug itself or of some products of decomposition. According to Babcock, the palsies occur irrespective of the use of adrenalin, glucose, alcohol or other constituents in the preparation. Whatever the explanation, the fact remains that ocular palsies occur once in every four or five hundred cases, although there has been a larger series in which there have been no palsies at all. In Richards' series there were none, in Sellheim's only 0.1 per cent; in that of Delaup and his associates there were 2,000 cases with no palsies. Babcock met with it five times in 2,000 cases. The palsy, appearing from seven to twelve days after the injection, involves usually one abducens, lasts for a few days to several months and rarely is permanent. It occurs most frequently after the high injections. Vertigo is an occasional complication lasting for days or weeks. In addition to ocular palsies there have been paralyses of the peroneus nerve and a violent neuritis of the sciatic nerve. Paresthesia and neuralgia of the legs are recorded by Helm and one of his patients had a syndrome not unlike that of tabes for one year, and two patients had sensory disturbances in the arms, but only of transitory duration. Transitory paralysis of the vesical and anal sphincters is by no means an uncommon sequel. Two fatal cases of paraplegia, followed by softening of the brain, were recorded by Guinard, and an extraordinary example of complete paralysis of the arms, legs and muscles of the neck, from which the patient fortunately recovered, was observed by Reynier. Trophic disturbances take the form of gangrene of the buttocks and extremities.

Catastrophes upon the operating table, such as *syncope, shock or collapse, and respiratory failure,* have been dealt with in the section on

mortality. The most alarming of these, respiratory failure, is due to the toxic effect of the drug. I have observed it in two cases, once after a low injection in an operation upon the spinal roots for spastic paraplegia, and once after a high injection in my clinic by Jonnesco in an operation for carcinoma of the breast. Both patients recovered after the head of the table was lowered, atropin given hypodermatically and artificial respiration continued until the respiratory apparatus regained its function. Curiously enough collapse may not make its appearance for several days. In many instances during or immediately after the injection a feeble pulse, slight nausea and pallor have been observed. The latter Barker attributes to a cerebral anemia from the complete relaxation of the abdominal muscles and the consequent filling up of the veins in the splanchnic area.

Failures.—In a certain percentage of cases the injection fails of the desired result altogether or in part. In some instances there is no anesthesia, in some it is either delayed or of too short duration, in some again the anesthesia is incomplete or limited to one side or the other. Failure of one kind or another has been variously attributed to faulty technic, idiosyncrasy of the patient or inertness of the drug. If the lumen of the needle be not entirely within the dural sac, some of the fluid will escape into the epidural space. If the patient lie on one side or the other, the heavier specific gravity of the solution will bring it in contact with the roots of only one side. The admixture of blood with the agent or prolonged boiling of the solution may render it inert.

The following is a statement of the percentage of complete failures:

Barker	2,354 cases	0.5 per cent
Deetz	126 "	3.1 " "
Becker	135 "	8.8 " "
McCardie	11,745 "	9.3 " "
Hohmeier and Koenig	2,400 "	9.0 " "
Sellheim	1,000 "	2.3 " "
Helm	1,419 "	7.4 " "
Richards	500 "	7.6 " "

Partial failure, when a general narcotic was required as an auxiliary measure, was reported by Barker in 4.2 per cent, by Babcock in 5 per cent, and by Sellheim in 11.6 per cent. In 228 abdominal operations Deetz used a general anesthetic 23 times, in 201 gynecological operations Stiven found it necessary to employ general narcosis in 19, and in operations lasting over an hour Sellheim's cases required a general anesthetic in 5.4 per cent.

Advantages and Disadvantages.—The advantages of spinal anesthesia over general narcosis are said to be somewhat as follows: it requires but five to ten minutes to produce analgesia; it obviates the necessity of an anesthetist; during the operation it secures muscular relaxation and quiet-

ude and is less apt to produce vomiting. After the operation vomiting is less frequent; pulmonary and renal complications are less common; it adds to the patient's comfort. It is said the blood pressure is not seriously affected; theoretically, at least, a "block" is established and shock thereby controlled. For these several reasons spinal anesthesia is said to be a means of reducing the operative mortality.

Contrasted with these alleged advantages, there are decided disadvantages. The method is not so safe as ether narcosis in the hands of those who use it but occasionally. Once the injection is made, the surgeon cannot control the toxic effects of what may prove to be an overdose. The subjective discomforts after the operation, especially headache, are intense. There is a distinct disadvantage in the preservation of consciousness in many individuals. There are too many elements of uncertainty concerning the degree of anesthesia, its extent and duration. In a considerable percentage ether must be used as an auxiliary.

Indications and Contra-indications.—The routine employment of spinal analgesia in any of the large clinics is exceptional, and there are many clinics where it is not employed at all. At one time I resorted to spinal anesthesia in exceptional instances, but since the introduction of nitrous oxid-oxygen as an anesthetic for major surgical operations and the perfection of the technic of local anesthesia, I find that the occasions in which spinal anesthesia seems clearly indicated as a life-saving procedure occur at increasingly long intervals. In strangulated hernia, in severe crush injuries of the extremities, in operations upon diabetic subjects, for prostatectomies upon patients with damaged cardiorenal apparatus, I was wont to use spinal anesthesia in preference to ether. To-day, infiltration anesthesia combined with nitrous oxid-oxygen narcosis enables one to perform any of these operations at a risk appreciably less than with ether, chloroform or under spinal anesthesia.

At one time spinal anesthesia was believed to be a panacea for those grave conditions in which general narcosis was contra-indicated, for the bad surgical risks where an operation under general narcosis seemed inevitably fatal. Wider experience has demonstrated conclusively that, from the standpoint of safety, spinal anesthesia has its limitations, and that under certain conditions the operative risks are quite as great as under general narcosis. Thus, even among its greatest advocates, Barker would exclude as contra-indications extreme asthenia due to carcinoma, the grave toxemia of intestinal obstruction or peritonitis; Babcock, patients with fatty hearts, great obesity, embarrassment of respiration from large pleural effusion, intrathoracic growths, advanced pulmonary disease. Babcock rejects it as dangerous in profound shock, in advanced sepsis, in grave toxemia; Ryall, when there is a high temperature, when the patient is of an hysterical or nervous temperament. All are agreed that it is not a suitable anesthetic for children. While one can readily enumerate the

contra-indications, it is very much more difficult to find any specific *indications.* Certainly it is not a safe anesthetic under any circumstances, except in the hands of one well accustomed to the technic of spinal injections, and even for those who know the pitfalls, the risks on and off the table, spinal anesthesia should be employed only for operations below the diaphragm and preferably only for operations on the pelvis, genitalia, rectum and extremities. A rather exceptional indication is the plating of fractures in elderly people where muscular relaxation is essential and ether narcosis hazardous because of advanced cardiorenal or cardiovascular disease.

Blood Pressure.—In the study of the variations of blood pressure associated with lumbar puncture and the production of spinal analgesia, Gray and Parsons came to the following conclusions:

"1. In lumbar puncture the puncture of the skin is accompanied by a rise in blood pressure which varies in extent with the degree of consciousness, the pain, and the disturbance produced by the operation, but which is not accounted for entirely by these factors. Puncture of the dura causes a much larger rise, which is due, not to pain or the disturbance produced, but to a definite effect on the vasomotor center.

"2. Withdrawal of cerebrospinal fluid tends *per se* to lower the blood pressure, but the net result of lumbar puncture is to raise it for at least twenty minutes afterwards.

"3. The type of blood pressure chart obtained in lumbar puncture, when the increased intracranial pressure is of subtentorial origin, is the same as that obtained in normal individuals; or as that obtained when the increased pressure is of supratentorial origin, but in the subtentorial types the variations are less pronounced. In subtentorial cases the rise is more sustained.

"4. Blood pressure records from cases of high spinal anesthesia show at the outset an abnormally high blood pressure, due to mental anxiety; then a rise following lumbar puncture; next a 'preliminary fall,' followed by a further more marked 'main fall' as the paralysis affects the thorax. Finally, as the paralysis passes off, the blood pressure rises to its original value. The 'preliminary fall' is due to:

(*a*) Flaccid paralysis of the abdominal and skeletal muscles.

(*b*) Subsidence of the disturbance caused by lumbar puncture.

(*c*) Onset of mental calm, amounting possibly to a sleep.

"The 'main fall' is due to the thoracic paralysis, which is not compensated for by overaction of the diaphragm, and consequently the aspiration action of the thorax is diminished.

"5. Marked deviations from this common type of chart are due to:

(*a*) Voluntary inspirations by the accessory respiratory muscles, and

(*b*) to a lesser extent by the activity of the higher centers.

"6. Variations in the pulse rate do not closely follow those of the blood

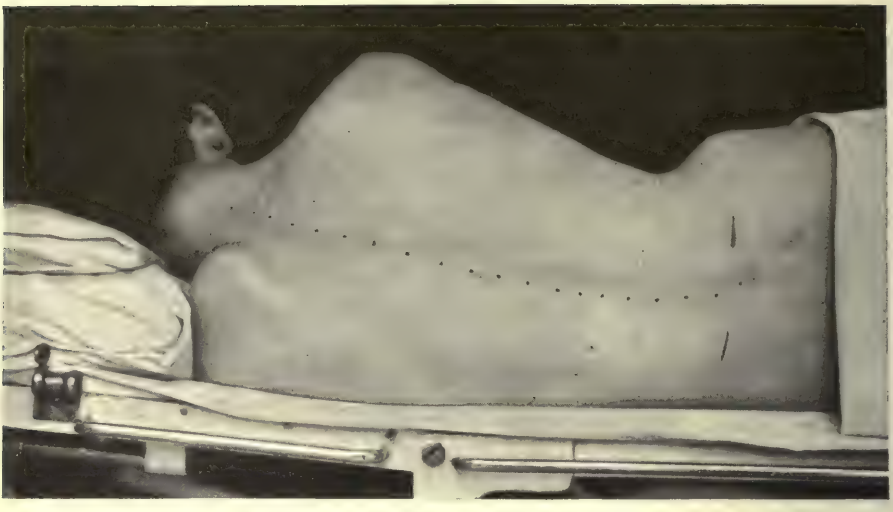

FIG. 327.—THE EFFECT OF POSTURE UPON GRAVITY WITHIN THE SPINAL CANAL IN SPINAL ANESTHESIA.

With the patient lying on the side, the lowest point in the canal would be at about the level of the first or second lumbar vertebra.

FIG. 328.—THE EFFECT OF POSTURE UPON GRAVITY WITHIN THE SPINAL CANAL IN SPINAL ANESTHESIA.

By elevation of head and shoulders, the lateral curve and sagging in the thoracicolumbar region are obliterated so that the lowest level of the spinal canal is in the sacral region.

pressure, but a certain degree of resemblance is often seen, owing to the consciousness of the patient.

"7. Vomiting during spinal anesthesia is due to thoracic paralysis which induces either:

(*a*) Anemia of the medulla, or

(*b*) Excessive action of the diaphragm, which interferes with the stomach.

"8. Blood pressure records from cases of low spinal anesthesia show the 'preliminary fall' but not the 'main fall.' The 'preliminary fall' in these cases is due to:

(*a*) Subsidence of the disturbance caused by lumbar puncture.

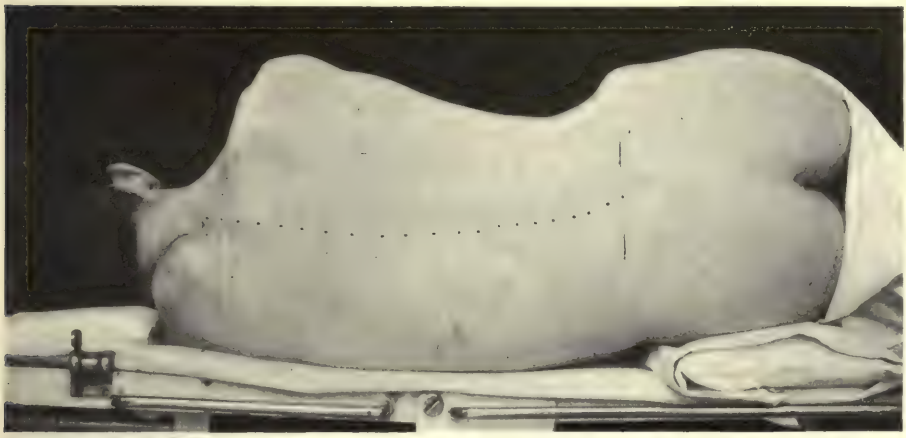

FIG. 329.—THE EFFECT OF POSTURE UPON GRAVITY WITHIN THE SPINAL CANAL IN SPINAL ANESTHESIA.

With the pelvis elevated by a pillow, the lowest level of the spinal canal is in the mid-thoracic region.

(*b*) Onset of mental calm.

(*c*) In some cases from the degree of flaccidity of the abdominal muscles.

"9. In the supine position there is no stagnation of blood in the great vessels, even when a very high spinal anesthesia is induced."

Technic.—In the intelligent use of spinal anesthesia a knowledge of the physiology of the cerebrospinal fluid, of the structures involved in lumbar puncture and of the properties of the anesthetic agent as prepared for injection are obligatory.

The circulation of the anesthetic solution within the dural sac is influenced by two factors: the position of the patient and the specific gravity of the solution employed (Figs. 327-329). The third factor, the to-and-fro circulation of the cerebrospinal fluid, if there be such, is negligible. The normal movement of the cerebrospinal fluid is from above downward and there are no grounds for implying that this current is reversed.

On the contrary, in the cervicothoracic region of the cord there are valve-like processes of the arachnoidal membrane which interfere with the passage upward of fluid unless injected with great force.

There are but two *anesthetic agents* worthy of consideration—stovain and tropacocain. Both have a pronounced influence, not only upon the sensory but upon motor nerves as well, so that muscular relaxation and paralysis of the sphincters accompany the analgesia. Both may be boiled without decomposition, both are soluble in water. It is claimed for tropacocain that it is less irritating and less likely to be attended with complications, that analgesia occurs sooner and is of longer duration. The fundamental difference between the various solutions employed is their specific gravity. This question has been so admirably and exhaustively investigated by A. E. Barker that I quote him at length:

To observe the general behaviour of various fluid compounds when injected into the spinal canal I had made many months ago a number of ½-in. glass tubes bent as accurately as possible to the curves of the spinal canal, as seen in Braun's frozen section of an adult lying on the back (Fig. 330). These tubes are

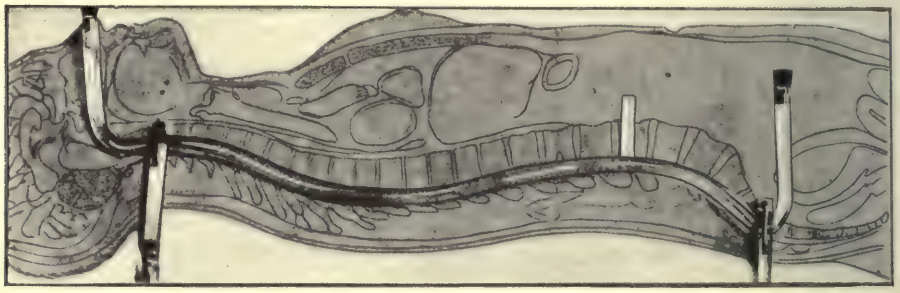

FIG. 330.—PHOTOGRAPH OF A TRACING FROM BRAUN'S WELL-KNOWN PLATE OF A FROZEN MESIAL SECTION OF THE FEMALE CADAVER LYING LEVEL. (Details omitted for the sake of clearness.)

Over the spinal canal, and following its curves accurately, is a glass tube filled with saline solution of the same specific gravity as that of the cerebrospinal fluid, 1.0070. Through the middle vertical arm over the second lumbar interspace, the hollow needle has been introduced into the curved tube, and 1 c.c. of Chaput's solution (specific gravity 1.0831) colored with methyl violet has been slowly injected. This has run rapidly into the dorsal curve, and at the end of two minutes is seen as a dark stratum opposite the fifth and sixth thoracic vertebrae. The dark area in the cervical portion of the tube is a shadow on the glass. (After Barker.)

turned up at each end for 3 in., and have another vertical tube rising to the same height as the ends fused on to them at a point corresponding to the second lumbar interspace (Figs. 330-332). When filled with a solution of sodium chlorid of a specific gravity of 1.0070 they may be held to represent roughly the spinal dura from the foramen magnum to its sacral end filled with its fluid, but minus the cord, which is not material for our present purpose.

These tubes accurately adjusted over a tracing of the canal in Braun's plate and filled with a saline solution (specific gravity 1.0070) have been used at various inclinations of the body to observe what occurs, at all events *in vitro,* when the different compounds now in vogue for spinal analgesia are injected into the lumbar

sac. Of course, it is conceded that certain vital phenomena would modify the conditions somewhat. But, in the main, what occurs here furnishes us with fairly correct evidence on most of the simple physical points connected with these injections in the living patient.

Each of the compounds to be injected has been coloured with the same quantity of methyl violet and used at the ordinary temperature of the air and of the saline solution filling the tube. It has been gently passed into the latter as on the living patient with the usual needle through the vertical arm over the second lumbar interspace. The figures are from photographs of the conditions actually present in the tubes *in situ* over Braun's plate two minutes after injection. But as the photographer had difficulties with the shadows on the glass thrown by the plate behind, I have had photographs taken of the tubes alone without Braun's plate, the level of the tubes relative to one another being the same.

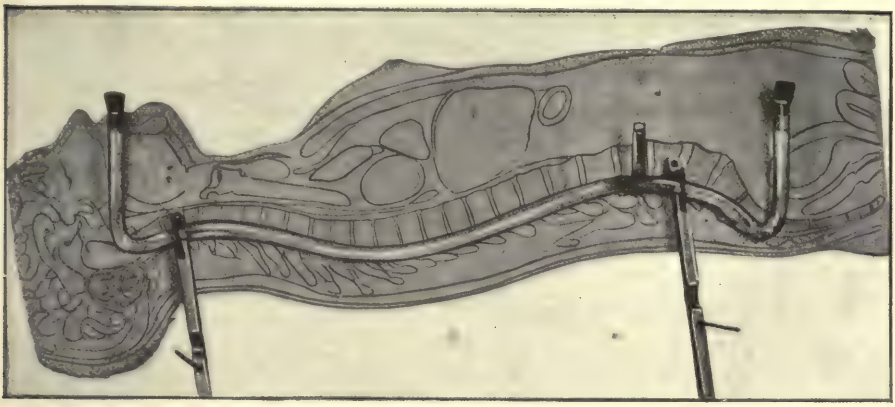

FIG. 331.—SAME AS FIG. 330, BUT WITH THE PELVIS RAISED 3 INCHES FROM THE LEVEL. In this case 1 c.c. of Bier's solution has been similarly injected, colored. This, having a specific gravity of only 1.0058, has not altered its position, except that, being lighter than cerebrospinal fluid (1.0070), it has risen in the vertical arm. In this position it remains for a long time undiffused. (After Barker.)

From Braun's frozen section of the cadaver lying on its back (Fig. 330) it may be seen that the highest point of the canal from the level is in the cervical region, and next to this a point between the third and fourth lumbar vertebrae, that is, the point at which the puncture for spinal analgesia is made. From this last point the dural tube slopes downwards in both directions. The caudal incline ends for the dura opposite the third sacral vertebra. The cephalic incline slopes from the point of puncture downwards as far as the fifth or sixth dorsal vertebra, when it begins to run upwards again to reach its highest point at the third cervical vertebra. With the head thrown forwards on a pillow, as the writer believes it should always be during intradural injection with heavy fluids, the foramen magnum would be the highest point in the spinal canal. These curves vary considerably in individuals and at different ages, but the above may be taken as generally correct. Now, if it were possible to puncture the lumbar sac from behind at the classical spot, with the patient lying on the back perfectly horizontal, a liquid heavier than the spinal fluid would always flow for the greater part from the injection needle towards the dorsal curve and settle in a layer about the fifth dorsal spine, while some of it would gravitate to the caudal end. This is actually what happens when the experiment is made with the glass tube bent accurately

to the curves of the spinal canal (Fig. 330). But in the living body there are practical difficulties in puncturing from behind with the patient supine. However, if the injection be made while the patient lies on the side, or face, as I have occasionally done, and he then turns over on the back with the head thrown forward, a heavy fluid should take the same course. That it does so is almost proved by the regularity with which the analgesia produced by the Chaput's heavy saline

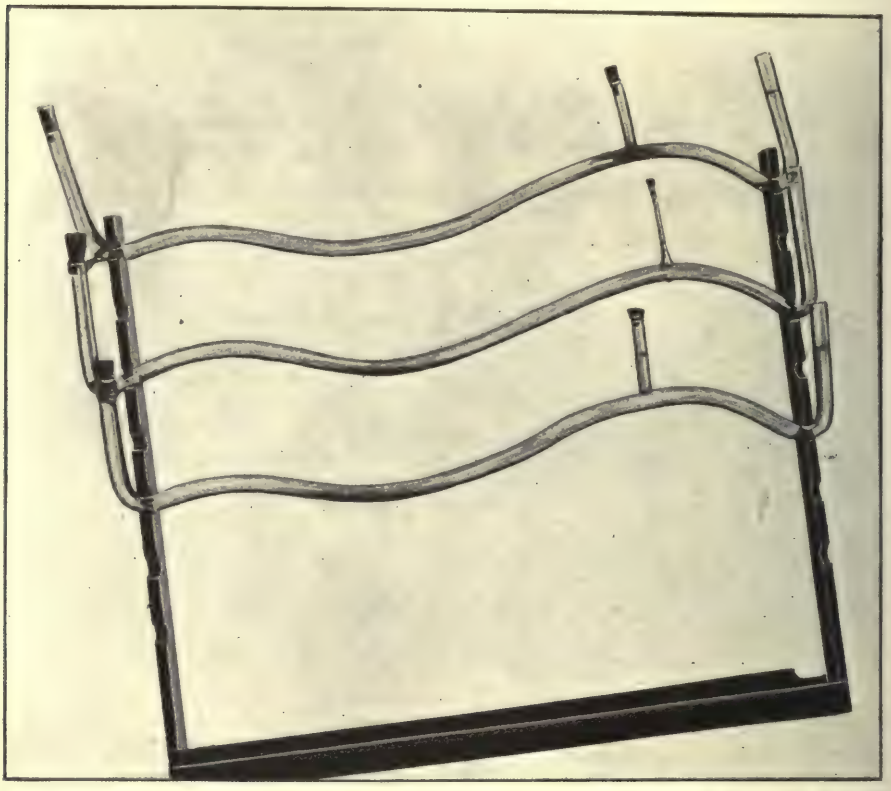

FIG. 332.—THREE TUBES AS IN FIGS. 330 and 331, BUT WITHOUT THE TRACING BEHIND.

Into the top one Bier's light solution has been injected, into the middle tube glucose-stovain (Barker's solution, specific gravity 1.0300), and into the lower tube Chaput's. The pelvis has been raised 3 inches as before. In the top tube Bier's compound, being lighter than the fluid in the canal, has remained stationary; the glucose-stovain, 1.0300, is still running down. Chaput's, the heaviest compound, has already reached the thoracic curve and is at rest. Photographed two minutes after injection. (After Barker.)

stovaine-sodium chloride compound or the writer's stovaine-glucose one, though not quite so heavy, rises to about the episternal notch or a little higher—that is, the region supplied by the sixth and seventh dorsal nerves. This varies a little, according as the head and neck are raised, and so the dorsal curve is increased. This was so frequently observed in the second fifty cases, where the glucose-stovaine compound was alone used, as to be remarkable. Of course, this may be modified somewhat by raising the pelvis a little, as has usually been done to hasten the flow of the injected fluid towards the dorsal curve before it becomes diluted by diffusion. It must not be forgotten, however, that in raising the pelvis while the

head and neck are supported forwards on a pillow, the lumbar curve is diminished, while that of the dorsum is increased. And the pelvis would have to be raised very high indeed to bring the level of the dorsal curve at the fifth or sixth spine above that of the foramen magnum, with the head and neck bent forward as described. There is, therefore, but little likelihood of the heavy compound reaching the medulla, or even into the cervical region at all. In some cases in Germany inversion has been carried to a very extreme degree, the head being unsupported, with the idea of displacing the whole mass of cerebrospinal fluid towards the cranial cavity. But we must remember that in these cases the compounds have usually been of low specific gravity, and in the case of Bier's actually lighter than the spinal fluid, so that it would not be likely to move as far as the neck by any oscillation of the column of the spinal fluid. There have been a few cases, however, both in France and Germany, in which the analgesia has extended over the whole head as well as the rest of the body without injury, but the details as to injection and pelvic elevation are not given. They were probably instances of diffusion helped by oscillation. Personally I have never aimed at getting a higher analgesia than to the transverse nipple line. At the caudal curves the effects of a heavy compound can be limited in the same way by position. If the patient be seated on the edge of the operating table with his feet on a low chair and his back rounded the heavy fluid injected at the second lumbar interspace at once tends to run into the sacral dura, as we see also in our tube experiment. Here it accumulates at the end of the dural sac, where it quickly affects the roots of the nerves supplying the parts about the anus and the perineum. This is seen so constantly, even where analgesia is less satisfactory in other parts, that it suggests that when the injection is made in the sitting position most of it makes its way caudally, and it requires much and immediate elevation of the pelvis and oscillation of the cerebrospinal fluid to dislodge it from the sacral sac. That is why I have thought it well in some cases to puncture with the patient lying face downwards, with a hard pillow crosswise under the umbilicus, so as to decrease the lumbar curve. In this position a heavy fluid runs toward the head, and if after half a minute the patient roll over on the back, and have a pillow placed under the head and neck pretty high, the injected fluid collects in the lower dorsal curve. This prone position, otherwise desirable, has the defect that the flow of cerebrospinal fluid is not so good unless the patient is told to raise his head and to bear down. But I think this can be overcome. But so great is the tendency for the injection fluid to be in part locked up in the sacral sac when the injection is done in the sitting position that if I want the analgesia to reach to the border of the ribs for an abdominal operation the patient is placed on the side with the knees drawn up as high as possible for puncture, and thus all the compound flows at once upwards and all of it collects in the dorsal curve as the patient rolls over on the back. In such cases where the patient remains for any time on the side after the puncture, we have noticed that the analgesia reaches higher up at the end of the operation on the side on which he has been lying. This seems to indicate clearly that the bulk of the compound has run along the roots on that side, but that it ultimately becomes segmental, affecting both sides, though still unequally.

Which of three solutions should be used, (1) that with the higher specific gravity to which glucose is added (Barker), (2) that with a lower specific gravity than the cerebrospinal fluid to which 10 per cent of absolute alcohol is added, or (3) a simple isotonic solution with normal saline solution as the menstruum, is left to the judgment of the individual operator. The fluid with the heavier specific gravity may be said to be the

least dangerous, as it can always be controlled by the position of the patient. Glucose is unaffected by the surrounding media and the specific gravity unaltered at least until the physiological influence of the drug has been spent. On the other hand, alcohol, by its attraction for water, may become a negligible factor and the specific gravity of the solution correspondingly affected.

The position in which the patient is placed after the injection will depend upon the specific gravity; with the lighter specific gravity of the alcoholic solution the patient is placed in the Trendelenburg position, with the heavier specific gravity of the glucose solution in the reverse position.

The following are the solutions from which selection may be made:

No. I. Babcock solution No. 1. Sp. gr. 1.0066

Stovain	0.08 gm.
Ac. lactic	0.02 c.c.
Absolute alcohol	0.2 c.c.
Aq. dest. q.s.	2. c.c.

This solution is put in ampoules of 2 c.c. by Frank E. Morgan & Sons, Philadelphia, each ampoule containing 0.08 gm. of stovain, and, before injecting, it is diluted one-half with cerebrospinal fluid.

No. II. Babcock solution No. 2. Sp. gr. 1.012

Tropacocain	0.1 gm.
Absolute alcohol	0.2 c.c.
Aq. dest.	1.8 c.c.

No. III. Barker's solution. Sp. gr. 1.023.

Stovain	5 per cent.
Glucose	5 per cent.
Aq. dest.	90 per cent.

The average dose for this solution is 5 cg. (1 c.c. of 5 per cent solution); the maximum dose is 6 cg., and the minimum 3 cg. This solution, prepared in glass ampoules containing 2 c.c., is a slightly viscid fluid which does not mix rapidly with the cerebrospinal fluid and sinks in a thin stream to the lowest level it can find and remains for a long time undiffused.

No. IV. Bier's solution No. 1. Sp. gr. 1.0058

Stovain	4 per cent.
Sodium chlorid	0.11 per cent.
Epirenin borate	0.01 per cent.

No. V. Bier's solution No. 2. Sp. gr. 1.030

Each ampoule contains:

Tropacocain	1.3 c.c. 5 per cent. solution
Adrenalin chlorid	0.00013 per c.c.

There are various ways in which the solution may be secured or prepared. The most satisfactory solutions are those put up in ampoules by

FIG. 333.—SPINAL ANESTHESIA IN SITTING POSTURE.

The syringe contains 1 c.c. of 4 per cent stovain solution, preparatory to diluting with an equal amount of cerebrospinal fluid.

FIG. 334.—SPINAL ANESTHESIA IN SITTING POSTURE.

The piston of the syringe has been withdrawn until the stovain solution has been diluted with an equal amount of cerebrospinal fluid.

competent chemists, as the stovain ampoules of Frank E. Morgan & Sons of Philadelphia. Tablets of the various anesthetic agents may be purchased sterilized, and when ready for use dropped and dissolved in the cerebrospinal fluid drawn into the barrel of the syringe. Whatever the agent or the method of preparation it should be freshly prepared—that is, within two weeks—and this is particularly true when adrenalin is one of the ingredients. Many of the failures and disasters have been attributed to decomposition. It is doubtful whether there is any advan-

FIG. 335.—SPINAL ANESTHESIA IN SITTING POSTURE.

The syringe has been slowly emptied into the spinal canal of its contents of equal parts cerebrospinal fluid and stovain solution.

tage in the addition of adrenalin to the solution, and while it may prolong the period of analgesia, it has been for the most part discarded.

The general principles that obtain in lumbar puncture should be borne in mind (*vide,* p. 757 *et seq.*). The *site* for injection *par excellence* is in the median line between the third and fourth or fourth and fifth lumbar vertebrae. At this level there is a space of 5 mm. between the right and left roots of the cauda equina, and if the needle puncture the dural sac in the median line, the roots escape injury. Prior to the injection a hypodermic of morphin sulphate .01 gm. in combination with atropin sulphate with or without scopolamin, .0002 gm., is given one hour and, if necessary, again twenty minutes before the operation. The *position* of the patient varies somewhat according to the specific gravity of the solu-

tion. When using the heavier or glucose solution Barker places the patient in the lateral position with head and shoulders elevated on a bolster so placed that the point to which the fluid is to gravitate represents the lowest point on the curve between the head and the pelvis. The patient retained in the lateral position, the roots on the upper side continue unaffected for a long time. This unilateral distribution of the analgesia is appropriate for the amputation of one extremity. Turning the patient on his back spreads the analgesia to the opposite side. For operations on the anal or perineal region the patient is placed in the sitting posture

FIG. 336.—INSTRUMENTS AND SOLUTIONS FOR SPINAL ANESTHESIA.
Iodin, alcohol, novocain, Record syringe, spinal needle, hypodermic needle, ampoule of stovain.

and the heavy solution gravitates to the lower portion of the dural sac and acts directly upon the sacral nerves (Figs. 333-335).

In the employment of his 10 per cent alcoholic solution with its lower specific gravity, Babcock reverses the position of Barker and places the patient in the Trendelenburg position. In this position the fluid diffuses caudalward. For prolonged analgesia the injection is made as near as possible to the roots which supply the field of operation. For operations on the perineum Babcock injects between the third and fourth lumbar vertebrae, for the extremities at the second interspace, for the lower abdomen at the first interspace, and for operation upon the abdomen, gallbladder or stomach, between the eleventh and twelfth thoracic vertebrae.

If the specific gravity of the solution be made neither heavier with glucose nor lighter with alcohol, but is isotonic, with normal saline solution as the menstruum, the injection is made with the patient in the sitting position and this position maintained for three minutes. The patient is then put in the recumbent posture and the operation proceeds.

The *requisite instruments and solutions* for spinal anesthesia include the following (Fig. 336):

5 per cent iodin solution
Hypodermic syringe and needle
0.5 per cent novocain solution
Straight Hagedorn needle
Lumbar puncture needle
2 c.c. Record syringe
Ampoule containing anesthetic agent

The solution may be boiled for fifteen minutes without loss of potency. The needles and syringe should be boiled in plain water; neither antiseptic nor alkalies should be used in their sterilization, as the former are irritating to the cord and the latter may render the anesthetic agent inert.

The Operation.—The patient is placed in one of the three following positions, according to which of the three solutions is to be employed:

1. Lying on side during injection, with bolster so placed at a point above which fluid will not gravitate (glucose solution).
2. Trendelenburg position (alcoholic solution).
3. Sitting posture (normal saline solution).

After the injection the position of the patient should be as follows:

1. Horizontal position with bolster beneath lumbar region (glucose solution).
2. Trendelenburg position (alcoholic solution).
3. Horizontal or slight Trendelenburg position (normal saline solution).

The point of election, usually the interspace between the fourth and fifth lumbar vertebrae, is determined as for lumbar puncture. A line on a level with the iliac crests traverses the spinous process of the fourth lumbar vertebra. The site of injection is anesthetized with 0.5 per cent novocain solution and the skin and fascia punctured with a Hagedorn needle. The analgesic solution is then drawn from the ampoule into a 2 c.c. Record syringe and the exact dose to be given estimated by the graduations on the syringe.

Each fifth of a cubic centimeter represents one centigram of the solution. The dose varies from 3 to 6 cg.; the average dose is 5 cg. The lumbar puncture needle is introduced in the median line at the site selected and if the dural sac have been punctured the cerebrospinal fluid should flow freely, the rate varying somewhat even in normal individuals. When there appears to be an abnormally high pressure and an excess of cerebrospinal fluid, the latter may be allowed to escape until the rate of flow approximates that of the normal. This is more accurately determined by the manometer. However, the anesthetic agent should not be injected until one is assured that the lumen of the needle is within the dural sac. The Record syringe is attached to the needle, the piston slowly withdrawn until the barrel of the syringe is entirely filled. As the syringe contained

about 1 c.c. of the anesthetic agent, it is diluted with an equal quantity of cerebrospinal fluid (Figs. 337, 338 and 339). The total mixture is slowly

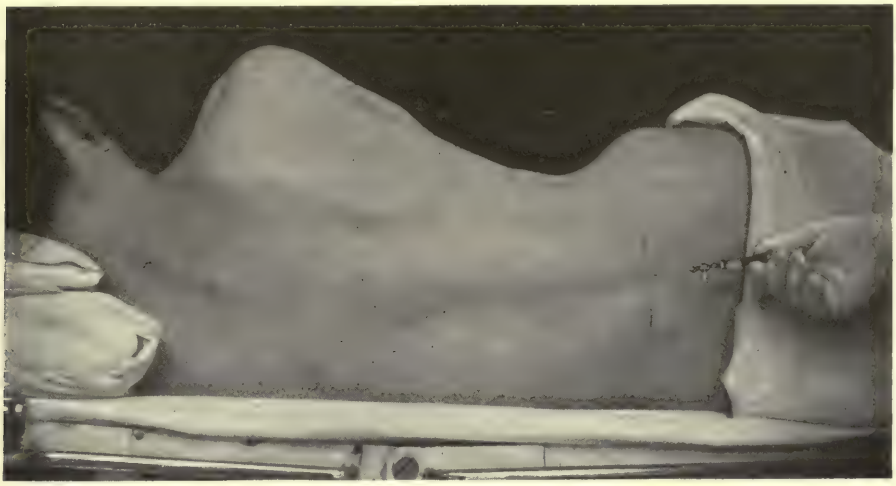

FIG. 337.—SPINAL ANESTHESIA IN RECUMBENT POSTURE.
The syringe is half filled with the anesthetic solution.

injected into the dural sac and the needle withdrawn. The patient is then placed in the position appropriate to the specific gravity of the solu-

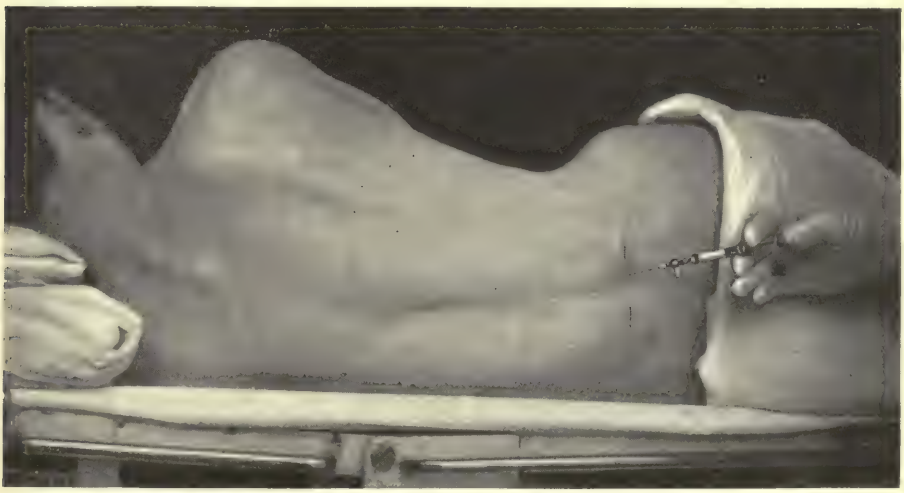

FIG. 338.—SPINAL ANESTHESIA IN RECUMBENT POSTURE.
The cerebrospinal fluid has been withdrawn into the syringe to dilute in equal parts the anesthetic solution.

tion employed and preparation made for the operation. In successful injection, analgesia will be evident in from three to seven minutes and is followed by loss of reflexes and partial or complete paralysis. The loss

of sensory or motor function varies with the strength and quantity of the solution. In the usual concentration there is almost complete loss of conduction in the motor and sensory pathways. The weaker the solution the less are the motor pathways affected. In many cases the sensory disturbance involves loss of the pain content of protopathic sensibility, not a loss of epicritic or touch sense, so that the patient may feel the pressure of the knife without a suggestion of pain. Immediately after the injection the pulse is reduced in frequency, increased in volume, and the patient looks and feels warm. Failing to attain the necessary analgesia there are three courses open to the operator: (1) a second spinal injection, which adds an undeniable element of risk, (2) infiltration anesthesia, or (3)

FIG. 339.—SPINAL ANESTHESIA IN RECUMBENT POSTURE.
The syringe has been slowly emptied of its contents into the spinal canal.

ether or nitrous oxid narcosis. In extremely nervous patients the state of consciousness upon the threshold of a major operation so unnerves them that light ether narcosis is welcomed. This was vividly illustrated in an elderly lady prepared for an amputation of the thigh. She felt the pressure of the knife and, though without pain, became so unmanageable that I found it necessary to direct the anesthetist to administer ether. The psychic effect of inhaling but a few drops of ether vapor under these circumstances is very striking and but a small quantity, not up to the point of unconsciousness, has the desired effect.

The appearance of *grave symptoms upon the operating table* is a signal for prompt and vigorous treatment. If the solution be isotonic or contain alcohol, no time should be lost in lowering the head of the table (exaggerated Trendelenburg posture). Under no circumstances, no matter what the solution, should the patient be allowed to sit upright, as this position has been attended with attacks of fatal syncope more than

once. For shock or collapse, atropin, camphorated oil and pituitrin should be given hypodermatically and repeated, if necessary. For respiratory failure resort to artificial respiration at first by the Sylvester method, substituting, when available, a pulmotor.

After the operation care must be exercised in moving the patient from table to bed that the proper position be maintained. Thus with the heavier solution, the head and shoulders must be kept above the level of the pelvis. With the lighter solution, alcoholic or normal saline, it is a wise precaution to keep the foot of the bed elevated for the first twenty-four to forty-eight hours and with the heavier solution the head of the bed should be elevated.

Of the after-effects headache is the most distressing, and its treatment therefore most urgent. The most efficient means of combating severe headache is the regulation of the cerebrospinal pressure; if low, normal saline solution may be given subcutaneously or by proctoclysis or an isotonic solution introduced by the lumbar puncture needle; and if high, the excess of cerebrospinal fluid, 5, 10 or 15 c.c., is withdrawn. Lumbar puncture may be repeated to advantage if headache recur and especially if the fluid be turbid. The usual remedies, such as the ice bag, aspirin, morphin, with small doses of atropin, may be tried but are of little avail.

Symptoms of collapse coming on after the operation are dealt with as already indicated: hyperpyrexia, by sponge baths; vertigo, by full doses of strychnin; and meningitis by repeated lumbar puncture. Nausea and vomiting, because of their central origin, are not influenced by anything that can be given by mouth.

EXTRADURAL CONDUCTION ANESTHESIA

Beginning with the discovery of the anesthetic property of cocain by Coupard and Borderon and its practical application by Koller and others in 1884, the combined efforts of the physiologist and the surgeon have been utilized in perfecting the methods whereby extensive areas of the body may be rendered insensitive to painful influences, and under whose sway even the most extensive of modern surgical procedures may be carried out painlessly and with full consciousness of the patient.

The topical use of cocain on mucous membranes was soon followed by its employment in subcutaneous infiltration, and as early as 1885 the first conduction anesthesia was practiced by Harlstedt when he injected cocain along the main branch of the inferior alveolar nerve. In this same year Corning made the significant observation that by injecting a two to three per cent solution of cocain between the spinous processes of the lower thoracic vertebrae, anesthesia of the lower limbs followed both in

dog and in man. Whether this solution of Corning actually reached the subarachnoid space is problematical. His idea was to deposit the injection in the region of the cord but outside the dural sac, and as such this constitutes the first attempt at paravertebral anesthesia.

Conduction anesthesia represents the most perfect type of local anesthetic methods. It contemplates the anesthetization of the main trunk of a nerve, and through this, with the employment of a comparatively small amount of the anesthetic agent, the loss of sensitiveness to pain of a greater or lesser region of the body may be induced. At first these injections were made endoneurally. This necessitated exposure of the nerve often by an extensive, time-consuming, and in itself painful dissection. While in isolated instances this means of infiltration may be preferable, the more simple percutaneous perineural method is far more commonly employed to-day. By this latter method, made possible largely through the discovery of comparatively non-toxic anesthetic chemicals, we aim to attain the same goal by depositing the dilute anesthetic fluid into the immediate neighborhood of the nerve and thence by diffusion to reach the nerve itself. This necessitates an accurate anatomical knowledge of the position and course of the nerves and their final distribution and the utilization of certain guides in the bones and soft tissues, which facilitate the carrying out of the injection. Obviously the time intervening between the introduction of the anesthetic and its permeation of the nerve with the appearance of anesthesia is much longer in the perineural than in the endoneural method.

Of all methods of inducing anesthesia, those of conduction are the most difficult, but at the same time they are the most desirable if successfully applied. While large nerve trunks or their important branches may be anesthetized at any point along their course with resulting anesthesia in their corresponding distribution, it is with its application to the nerves at or near the spinal column that we are here chiefly concerned. These special methods are known as paravertebral, parasacral and sacral anesthesias.

Paravertebral anesthesia may be employed by choice when the safety of the patient demands the abandonment of general narcosis. Practically every operation on the neck, thorax and abdomen may be performed under its influence, and although in recent years the technic of paravertebral anesthesia has been brought to a high degree of efficiency, it is doubtful whether it will be universally accepted. Kroenig has used paravertebral or parasacral anesthesia in 670 successive major operations without a death from the anesthetic, while 450 cases, or 66 per cent, showed no accessory reactions. It is unnecessary to withhold food before the operation; in fact the patient fares better when fed, and this is of advantage in debilitated subjects. There is no postoperative nausea, vomiting and straining; intestinal paresis with its resulting tympanites and gastric dilatation are

eliminated. Resumption of feeding can be instituted much earlier in the average case. But in children or in epileptic subjects and highly nervous or neurotic states, paravertebral anesthesia is contra-indicated.

The roots of the spinal nerves join within the vertebral foramina and immediately at their exit from the latter divide into an anterior and a posterior branch. From the anterior branch a filament is given off which runs forward to communicate with the sympathetic system (Fig. 340). In

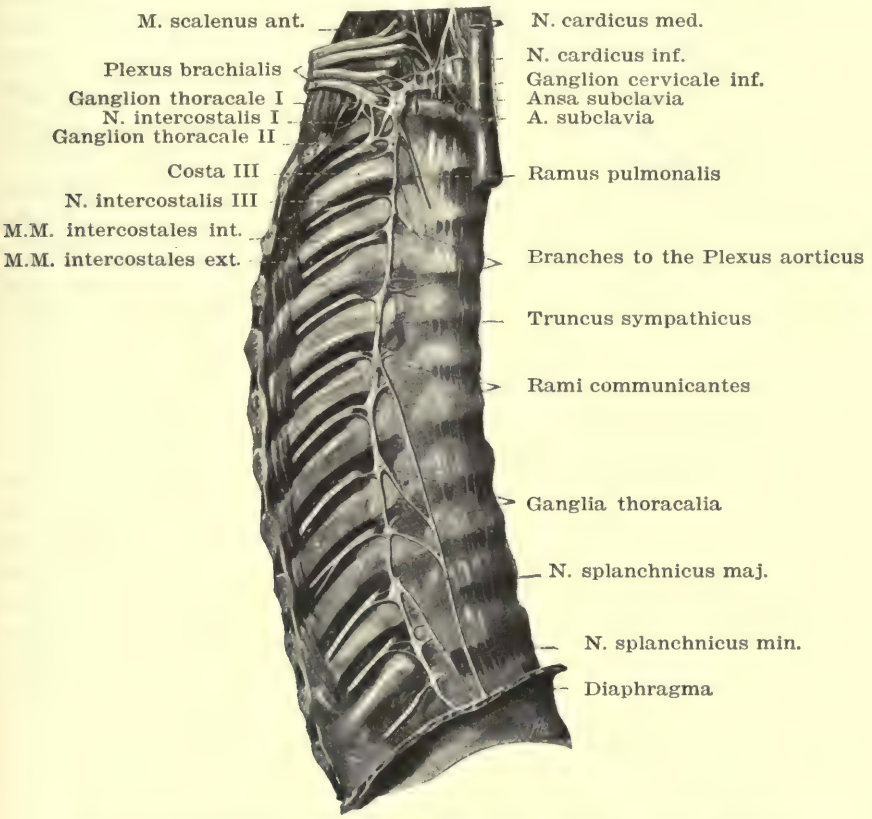

FIG. 340.—INTERCOSTAL NERVES AND THE SYMPATHETIC. (After Spalteholz.)

paravertebral anesthesia the effort is made to block the nerve immediately at its exit from the foramen and to catch, if possible, this communicating branch to the sympathetic. Injections within the foramen itself have been found dangerous, as the solution may penetrate the dura and reach the spinal canal, or the dura itself may be punctured and the injection made directly into the canal. These accidents have resulted in serious collapse, and for this reason it is advisable to infiltrate the nerves at a short distance from their points of emergence. In the average adult, if a line be drawn down the tips of the spinous processes and lateral meas-

urements made from this line on either side, the free intervals between the transverse processes will be found to lie two and one-half centimeters from the midline. These measurements hold good along the entire thoracic and lumbar regions of the spinal column. As the emergence of the nerves from the intervertebral foramina is shielded posteriorly by the lateral projections of the articular processes, a point somewhat further out—about one centimeter, thus making it from three and one-half to four centimeters from the midline—is best selected as the point of puncture so as to enable the needle to be directed inward and reach the nerves in the region of the foramen. If at this point, four centimeters from the midline, and on a level with a spinous process, a needle be introduced directly inward and perpendicular to the surface, its point will, in the thoracic region, come in contact with the surface of the rib next in number to the spinous process chosen. In the lumbar region the corresponding transverse process will be reached under the same circumstances. The lower border of the rib, or of the transverse process, is used as a further guide in reaching the neighborhood of the nerve which it is desired to block. In the cervical region, the tips of the transverse processes alone are available as guides to the cervical nerves.

The *agents* almost universally employed in place of cocain, which proved too toxic, are beta-eucain lactate and novocain; both are benzol derivatives. Beta-eucain, the free base, is almost insoluble in water, while beta-eucain lactate is soluble up to 22 per cent and is slightly less toxic. When injected into the tissues it is practically non-irritant, but produces slight vasodilatation. Opinions vary as to its toxicity. Clinical experience would seem to bear out the experiments of Vinci and others that it is from three to five times less toxic than cocain. Careful investigations by Piquand and Dreyfus, on the other hand, show its toxicity to be but slightly less than the latter drug. It is a little slower in action and a little less diffusible than cocain. It possesses the highly desirable quality of being capable of sterilization by boiling without affecting its efficacy, while its solutions may be kept for a considerable time without suffering deterioration. Owing to its slight vasodilator action the addition of adrenalin chlorid in suitable quantity just prior to injection is desirable and tends to retard the too rapid absorption into the circulation. The following formula is used for deep conduction anesthesia:

Beta-eucain lactate.....	0.5 parts
Normal saline solution.....	100 "

This solution should always be sterilized by boiling just before use, cooled, and the adrenalin added in the proportion of five drops of a 1:1,000 solution to each 30 c.c.

Beta-eucain lactate, while a most satisfactory substitute for cocain, has now been largely replaced by novocain, which possesses all its advan-

tages and others in addition. This drug presents almost the ideal qualities which are desirable in a local anesthetic. It possesses distinct advantages over all the other agents used for this purpose. It is of very low toxicity and absolutely non-irritant—two qualities of vital consideration. Novocain was introduced by Einhorn in 1905 and first extensively employed by Braun. It is soluble in equal parts of water and can be heated to 120° C. without decomposition. Its solutions can be repeatedly boiled without affecting their strength and may be kept for many months without deterioration. It has no action even in large doses upon either the circulation or the respiration. It is from five to seven times less toxic than cocain, while in 1.25 per cent solutions it is equal in anesthetic activity to 1 per cent solutions of the latter. Of much importance, however, is the fact that its action is greatly enhanced by the addition to its solutions of small quantities of adrenalin chlorid, so much so that its activity equals that of cocain. The salts of calcium and magnesium when added also tend to intensify its anesthetic powers. In the presence of these salts its anesthetic ability probably far exceeds that of cocain, and, though slightly slower in action, the duration of anesthesia is considerably longer. Novocain exerts but little influence upon the vasomotor nerves, its injection is painless, non-irritant and followed by no pain, inflammation or induration. It is unquestionably the safest, most reliable and most satisfactory of all local anesthetic agents.

Experience has shown that novocain in 0.5 per cent solution is strong enough to secure anesthesia in paravertebral injections. Moreover, this weak solution is of decided advantage in that it permits of the injection of large quantities without untoward effects—a matter of importance in perineural injections where reliance can be placed upon the larger quantities to reach the nerve with greater certainty. The accompanying illustration from an actual specimen shows the areas in shading that are infiltrated by from 5 to 10 c.c. of the solution at each point of puncture (Fig. 341).

A decided gain is derived from the addition of adrenalin chlorid to the solutions. By its vasoconstrictor action it retains the anesthetic in the tissues for a considerable length of time, from three and one-half to four hours. This not only intensifies the anesthetic action but eliminates to a considerable degree the possible toxic effects of its rapid absorption into the general circulation by keeping it within the tissues for such a length of time that its activity is largely weakened or destroyed. When absorption does occur it is so gradual that no constitutional effects are noted. Adrenalin itself has certain dangerous possibilities. Deaths reported occasionally from the use of local anesthetics seem to be due to the unreasonably large quantities of adrenalin used rather than to the anesthetic. Not more than 15 to 20 drops should be injected at one operation no matter how much anesthetic is used. Where extensive infil-

trations are used, as in paravertebral injections, the total amount of the anesthetic solution to be used should be measured off, and to this should be added the estimated amount of adrenalin. Synthetic adrenalin now on the market does not differ from the natural product, except that it possesses the advantage that it can be boiled for from three to five minutes without deterioration.

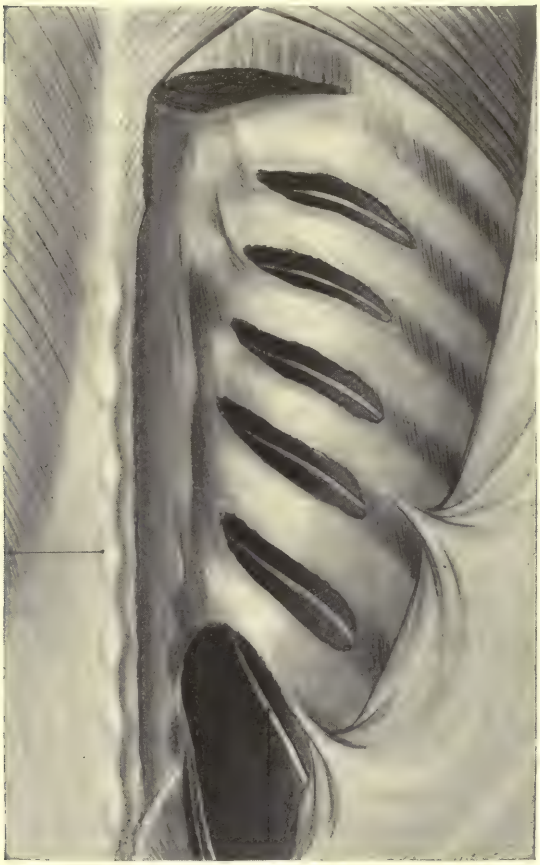

FIG. 341.—EXTRADURAL CONDUCTION ANESTHESIA IN THE THORACIC REGION.

Showing that entire space about intercostal nerve (*b*) to be blocked was infiltrated. *a*, Spinous process of the twelfth thoracic vertebra. (Kroenig and Siegel.)

Compressed tablets containing novocain and synthetic adrenalin in proper proportions may be obtained in the market and used to make the required solution. These tablets, however, are best used when only very small amounts are desired, as in making up any large quantity a very large number of tablets would be required. After dissolving the tablets in sterile saline solution or in sterile water the whole should be boiled for three minutes before using. By far the better way when large quantities are required is to keep a supply of novocain made up in powders or capsules of 0.16 gm. each. Each powder or capsule when dissolved in 30 c.c. of sterile water or saline solution will, therefore, yield a 0.5 per cent solution of the drug which is sterilized by boiling and the adrenalin added in the proportion of 5 drops to 30 c.c. just before using.

It has already been stated that the anesthetic action of novocain is prolonged and intensified by the addition to its solutions of the salts of calcium and magnesium. These advantages have been utilized by operators, notably Harris, in the preparation of their novocain solutions, using the following formula:

Solution 1.	Novocain	1.0	per cent.
" 2.	Calcium chlorid	2.0	" "
" 3.	Magnesium chlorid	2.0	" "

These are made up with sterile distilled water and kept separately. Solution No. 1 is boiled for three minutes, Solutions 2 and 3 longer, and all cooled to 89° C. Chloretone is then added to each solution to the point of saturation (one per cent oversaturates). The solutions must be cooled before adding the chloretone, and if the color of No. 1 become yellow, it is spoiled and should not be used.

The mixture, when ready for use, is composed of the following:

Novocain solution	three parts
Calcium solution	one part
Magnesium solution	0.5 parts

Finally, adrenalin chlorid (1:1,000) is added in the proportion of 5 drops to 30 c.c. just before using. The chloretone itself is slightly anesthetic and aids in the solution of the lipoids.

Equipment.—For carrying out the various methods of conduction anesthesia about the spinal column the following are needed: two or more syringes with a capacity of 5 or 10 c.c. each, preferably of the Luer all-glass or of the Record type; needles constructed from an alloy of platinum, 6 cm. in length for the thoracic region, 8 cm. for the lumbar nerves, and 15 cm. for parasacral injections; a 5 per cent tincture of iodin for local skin preparation, a fine hypodermic needle and barrel containing 0.5 per cent novocain solution for anesthetizing the skin at each point of deep injection, the desired quantity of anesthetic fluid, sterile cotton, sponges and towels to drape about the area exposed for injection and a small metal ruler graduated in centimeters.

Preparation.—Confidence on the part of the patient and freedom from apprehension are prime requisites to success in operating under local anesthesia. This is especially desirable in deep conduction anesthesia where presumably extensive procedures are contemplated and in nervous and debilitated subjects. Calmness, confidence and hopefulness will go far toward eliminating many of the difficulties, and are to a large extent reflective from the personality and attitude of the operator, assistants and other attendants. Just before the operation narcotics should be given in doses large enough to induce drowsiness and a certain happy indifference, the German "Dämmerschlaf," but never sufficient to produce somnolence. As a rule, one hour before operating a hypodermic injection of morphin sulphate, 1.08 to 1.62 cg., with atropin sulphate, .0432 cg., may be ordered, and one-half or three-quarters of an hour later this injection is repeated. Some operators prefer a combination of morphin and scopolamin, the latter in doses of .0432 cg. for the first injection. It is

usually neither necessary nor desirable to repeat the scopolamin with the second injection. Disturbing influences, such as loud noises and particularly light, should be avoided from the time the initial injection is given. The patient is taken to a quiet, darkened room, a soft bandage is tied over the eyes and the ears are plugged with cotton. With these precautions patients often remain mentally indifferent to the preliminary preparations and to the injections of the anesthetic.

FIG. 342.—THE TRANSVERSE PROCESS LINE ON THE NECK. (After Braun.)
a, b, Points of puncture.

TECHNIC FOR THE CERVICAL REGION.—*Method of Kappis.*—Kappis devised the posterior route of reaching and injecting the cervical nerves. The spinous processes are identified and a line immediately on either side of them is anesthetized by subcutaneous injection. A long needle is now advanced forward, close alongside the process whose corresponding nerve is to be infiltrated, until the transverse process is encountered. The interval between this process and the next is now sought with the tip of the needle, when the latter is advanced 1.5 cm. further and 5 c.c. of anesthetic solution injected.

Method of Heidenhain.—Braun has used extensively the cervical paravertebral injections suggested by Heidenhain and prefers them to the method of Kappis. The injections are made from the side, between the third and fifth cervical vertebrae at the point where the nerves lie close together. A line is projected on the neck from the tip of the transverse process of the atlas, which is felt under the point of the mastoid process, downward over the tip of the transverse process of the sixth cervical vertebra, the carotid tubercle. This line represents the point at which the long axis of the transverse processes reaches the surface and forms a sharp angle with the edge of the sternomastoid (Fig. 342).

Two injections are made on this line, the upper one on a level with the lower border of the inferior maxilla, the lower one on a level with the promontory of the larynx. From these two points the needle is carried directly inward until it comes in contact with the transverse processes

of the vertebrae, injection being made freely between the two points of puncture, *a* and *b*, deep down in a fan-like manner, in all from 30 to 40 c.c. of solution being used. The great vessels of the neck lying considerably in front of this line are free from danger. For operations crossing the midline of the neck both sides are injected, while, if the field of operation extend to the lower margin of the inferior maxilla, the third division of the trigeminal nerve must also be blocked. It is advisable to combine local infiltration anesthesia with the paravertebral injections in the cervical region. Cervical injections are somewhat more difficult and certainly the most dangerous forms of paravertebral anesthesia. The origin of the phrenic nerve from the third, fourth and fifth cervical segments is practically in the center of the field, while after its formation its course is more superficial. While no fatalities have been reported from phrenic involvement, the possibility of injury to this nerve, especially in bilateral injections, should not be forgotten.

Technic in the Thoracic and Lumbar Regions.—Krause, Heidenhain and the author have all performed laminectomy under local conduction anesthesia alone. In doing this operation, however, it is necessary to combine subcutaneous, intramuscular and subperiosteal infiltrations with the injection of the intercostal nerves and, if the dural sac be opened and the roots disturbed, the substitution of a general anesthetic is indicated unless the roots themselves be injected. Schumacher was the first to employ paravertebral anesthesia in thoracoplasty, and reported 35 of these operations, while Kappis first applied extensively the methods of Läwen in abdominal operations. Schumacher obtained complete anesthesia in 20 of his cases, while in 15 a light general anesthesia was necessary. When one must fall back upon an inhalation narcosis, it is seldom necessary to carry this beyond the light psychic stage. Kappis also removed the ninth and tenth ribs entirely and the greater portion of the fifth to the eighth and the eleventh by means of conduction anesthesia induced by blocking the spinal nerves from the fourth to the eleventh thoracic vertebrae. Hirschel, in performing thoracoplasty, makes his injections into the intercostal spaces not only posteriorly but also anteriorly, and circumvents the field of operation with subcutaneous infiltration. Following injection of the spinal nerves, the area of cutaneous anesthesia extends approximately to the area of distribution of the lowest nerve injected, while the upper limit lies one or possibly two ribs lower than the highest. It is necessary, therefore, to inject one or two ribs above the uppermost rib to be resected.

Paravertebral anesthesia has been applied to operations within the abdominal cavity. It is necessary to block only the thoracic and lumbar nerves innervating the corresponding segments of the abdominal wall within the limit of which the incision lies. Operations upon the stomach, intestines, kidney, gall-bladder and biliary passages are easily

carried out, because the nerve-blocking is relatively simple; the organs themselves are not sensitive. Procedures involving the pelvic generative organs, however, present difficulties and require in addition the combination of parasacral injections, because the peritoneal coverings of structures, such as the broad and round ligaments, are innervated by nerves from the lumbar and sacral plexuses. The frequent propinquity of the appendix to the pelvic organs and its relationship to the infundibulopelvic ligament explain the pain observed in some instances when an appendectomy is done under paravertebral anesthesia. Sacral or parasacral anesthesia might be advantageously combined with the latter in performing an appendectomy—a combination always necessary in pelvic surgery.

The following table (Table III) compiled by Kroenig from his observations on over 600 operations shows the nerves which must be blocked in the common abdominal operations, in what areas the addition of parasacral blocking is indicated and the total amount of novocain solution in terms of 0.5 per cent injected. The maximum amount used is 330 c.c. of a 0.5 per cent novocain solution, representing 1.6 gm., but it is interesting to note that Kroenig and Siegel have used as much as two grams without alarming effects.

The *Kappis technic,* which seems to be the most acceptable, is as follows: On the operating table the patient is placed, if possible, in the sitting posture; if not, in the lateral recumbent position, as for lumbar puncture. The spine of the fourth lumbar vertebra, identified as on the level with the iliac crests, is marked with iodin or silver nitrate. With the angles of the scapulae located, the level of the sixth or seventh thoracic vertebra is represented by a line connecting these points and marked as above. If the injections are to be given above the level of the sixth or seventh thoracic vertebra, the vertebra prominens is likewise identified and marked, and the intermediate spinous processes counted and marked. A line is drawn on either side of the midline and 4 cm. distant and along these lines the skin opposite the spines is anesthetized by hypodermatic infiltration, the wheals marking the points for subsequent puncture. The needle, 6 cm. long for the thoracic and 8 cm. long for the lumbar injections, is now introduced vertically along the line and on a level with the spinous processes, until it comes in contact, at a depth of from four to five centimeters, with the rib next in number to that of the spinous process. In the lumbar region, the transverse processes are used as guides instead of the ribs, and here the transverse process corresponds in level to that of the spinous process of the same vertebra. After locating the rib or transverse process with the tip of the needle, the base of the needle is carried upward and outward so that the needle may be directed at an angle of from 20° to 30° downward and inward until the lower border of the rib or transverse process is passed. The needle is then advanced two or three centimenters, the barrel attached and the injection begun.

TABLE III (KROENIG AND SIEGEL)

Appendectomy	Paravertebral	Right dorsal 5–12 Right lumbar 1–3 } Incl. @ 20 c.c. = 220 c.c. ½% = 1.1 grams
Nephrectomy	Paravertebral	Right or left Dorsal 4–12 Lumbar 1–3 } Incl. @ 20 c.c. = 240 c.c. ½% = 1.2 grams
Laparotomy for abdominal work	Paravertebral	Right and left Dorsal 5–12 Lumbar 1–3 } Incl. @ 15 c.c. = 330 c.c. ½% = 1.65 grams
Cesarean section	Paravertebral	Right and left Dorsal 9–12 Lumbar 1–3 } Incl. @ 15 c.c. Sacral (1–5) each side @ 60 c.c. } = 330 c.c. ½% = 1.65 grams
Laparotomy for pelvic work	Paravertebral	Right and left Dorsal 8–12 Lumbar 1–3 } Incl. @ 15 c.c. Sacral (1–5) each side @ 45 c.c. } = 330 c.c. ½% = 1.65 grams
Inguinal incision (bilateral)	Paravertebral	Right and left Dorsal 11–12 Lumbar 1–3 } Incl. @ 15 c.c. Sacral (1–5) each side @ 90 c.c. } = 330 c.c. ½% = 1.65 grams
Vaginal operations on uterus and adnexae	Paravertebral	Right and left Lumbar 1–3 Incl. @ 20 c.c. Sacral (1–5) each side @ 100 c.c. } = 320 c.c. ½% = 1.6 grams
Prolapse operation	Paravertebral	Right and left Sacral (1–5) each side @ 125 c.c. = 250 c.c. ½% = 1.25 grams

From 10 to 15 c.c. of the 0.5 per cent novocain solution are injected into each intercostal or interspinous space, the needle slowly withdrawn as the injection is made, so that when the required amount has been injected, the point of the needle will again be on a level with the surface of the rib or transverse process. The anesthesia is induced within five to fifteen minutes and lasts from one and one-half to two hours.

Parasacral Anesthesia.—Conditions governing conduction anesthesia in pelvic and perineal operations differ somewhat and are more difficult to control than in operations above the pelvic brim. The uterus and adnexa and their peritoneal covering, together with the broad and round ligaments, the vagina and perineum, are innervated by nerves from both the lumbar and sacral plexuses. A portion of their nerve supply, especially that of the round ligament, is derived from the lumbar nerves. Thus the genitocrural branch of the second lumbar, dividing into its external spermatic and lumbo-inguinal branches, supplies the inguinal region and the round ligament. Other important branches are the cutaneus femoris lateralis, a branch of the third lumbar nerve, and the ilio-inguinal and iliohypogastric from the first lumbar nerve. In every pelvic operation by the suprapubic route, therefore, not only the sacral nerves but also the first, second, and usually the third lumbar nerves must be blocked. The lumbar paravertebral injections serve to anesthetize the lower abdominal wall, the parietal peritoneum and the round ligaments with that portion of the peritoneum covering the uterus; the parasacral anesthesia serves for the anesthetization of the lower pelvic peritoneum and the remaining structures. Parasacral anesthesia alone serves for such operations as perineal prostatectomy, resection of the rectum, vaginal operations up to and including the cervix of the uterus and minor procedures in the perineal region, such as hemorrhoids and fistulae. It was first described and used by Braun, who thus blocked the sacral nerves immediately at their points of emergence from the sacral foramina. It is more reliable than sacral anesthesia and is without the frequent secondary effects of the latter.

The anterior sacral foramina lie almost in a straight line, which from below upward deviates outward at a very slight angle. The distance, on the average, between the midpoints of the first sacral foramina is 4.3 cm. and between the midpoints of the fourth foramina is 3.75 cm. The fifth foramen is formed by the sacrococcygeal articulation and does not appear as a separate opening. If, therefore, a line be drawn down the middle of the sacrum, a line passing over the centers of the foramina diverges but 0.3 cm. from this midline in passing upward from the fourth to the first foramen. The distance from the free margin of the sacrum at its lower free border, sacrococcygeal junction, along the line passing over the centers of the foramina, is 1.8 cm. to the midpoint of the fourth foramen, 3.7 cm. to the midpoint of the third foramen, 5.3 cm. to the

midpoint of the second and 7.8 cm. to the center of the first sacral foramen. Consequently, the foramina are the following distances apart: approximately 1.8 cm. from the fourth to the third, the same from the third to the second, while the first is 2.5 cm. from the second (Fig. 343). In the study of numerous cases by Allen, it was found that the intermediate foramina between the fourth and the first in some few instances are placed somewhat outside the straight line passing over the centers of the openings. This lateral variation, however, is usually but about 3 mm., and was never found to exceed 6 mm. If a needle be passed straight in over the free margin of the sacrum, that is, the margin below the sacro-iliac synchondrosis, 1.8 cm. from the midline and directed upward with a very slight outward deviation, it will pass directly over the fourth, third and second foramina, when it will come in contact with the promontory of the sacrum. Now, if it be slightly withdrawn and redirected with the point elevated and advanced 0.5 cm. further, it will reach the first sacral foramen.

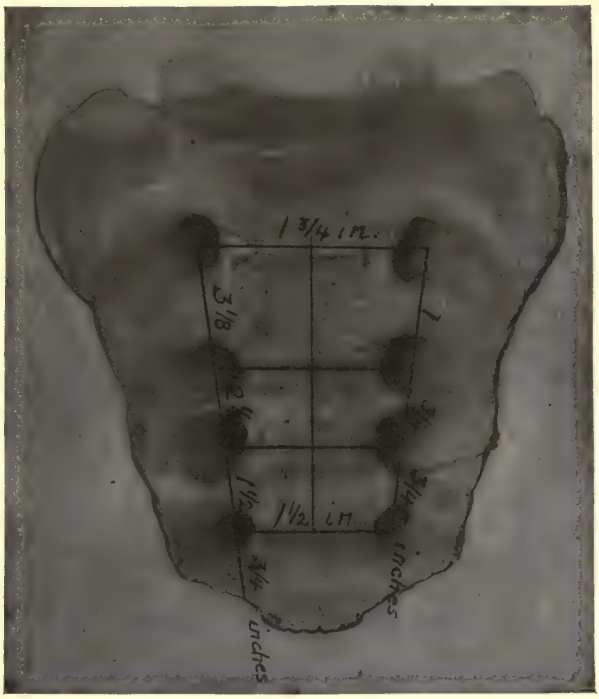

FIG. 343.—ANTERIOR VIEW OF SACRUM, SLIGHTLY REDUCED, SHOWING RELATIVE DISTANCES BETWEEN FORAMINA. (After Allen.)
In the text the measurements are given in centimeters.

These anatomical factors form the basis of the *technic* for parasacral conduction anesthesia which is carried out as follows: The needle should be from 12 to 15 cm. in length. The patient is placed in the lithotomy position. The tip of the coccyx is located and two points are marked, 1.5 to 2 cm. on either side of a midline and on a level with the tip of the coccyx. The needle is now introduced at one of these points and pushed forward along the surface of the sacrum until an obstruction is met. This usually occurs at a depth of from 7 to 8 cm. when the needle tip is at the second sacral foramen. The needle is now withdrawn 0.5 cm. and 25 c.c. of the anesthetic fluid injected. During the gradual withdrawal of the needle almost to its point of in-

section 35 c.c. of the anesthetic are injected; the third, fourth and fifth foramina are thus infiltrated. The needle is again pushed forward at a slightly greater angle to the sacral axis and parallel to it sagittally, until obstruction is again met at a depth of from 10 to 12 cm., when its tip will be at the first sacral foramen. Withdrawing it about 1 cm., 20 c.c. are injected. The needle is again withdrawn to the skin, its point inclined well inward and advanced between the coccyx and rectum, where 5 c.c. of the anesthetic fluid are injected. The same technic is repeated on the opposite side, in all from 100 to 150 c.c. of the anesthetic being used. Before making any of the injections it is well to remove the

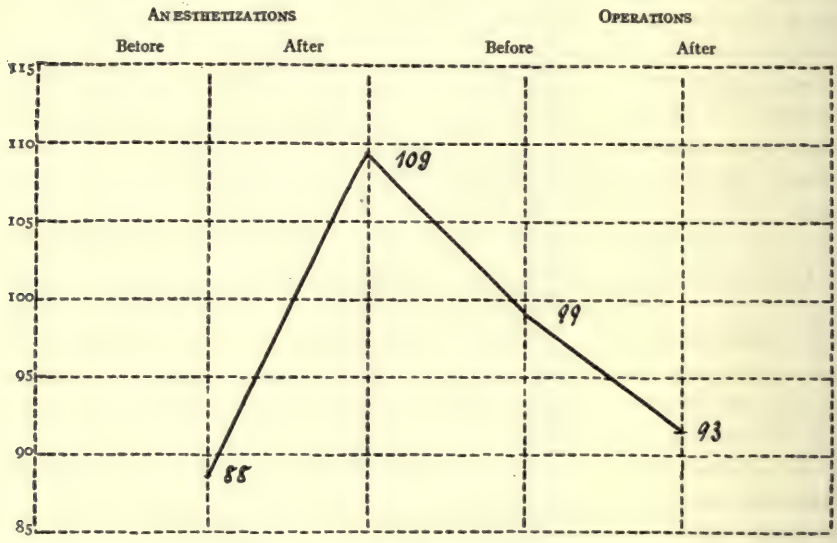

Fig. 344.—Pulse Curve Taken from 670 Successive Anesthetizations. (Kroenig and Siegel.)

barrel of the syringe or make a little suction with the piston. If blood appear, a vessel has been punctured and the direction and depth of the needle should be changed; otherwise the anesthetic may be thrown directly into the circulation with disastrous results. There is no danger of injuring the rectum if it be empty and the needle be directed close to the bone as it is advanced, since by so doing the rectum is pushed aside. If preferred, however, a finger may be inserted within the rectum for guidance. After an interval of five or ten minutes one may proceed with the operation with the probability that the anesthesia will persist for one and one-half to two hours—much longer than is usually required. The accompanying chart (Fig. 344) shows a rise in pulse rate to 109 beats per minute after anesthetization; a gradual fall to 99 at the beginning of the operation, and a further gradual fall to practically normal toward the end

of operation. In the same series the average respiratory rate was but 19 per minute with no marked variation.

The appended chart (Fig. 345) conveys clearly the infrequency of accessory reactions. Over 60 per cent of all cases will show no complication, and in all Kroenig's experience no death directly traceable to the anesthetic is recorded.

While one must not be too confident of success in all cases, the results obtained in large series are very encouraging. At times a nerve or nerves may be missed, escape anesthetization, and necessitate the addition of

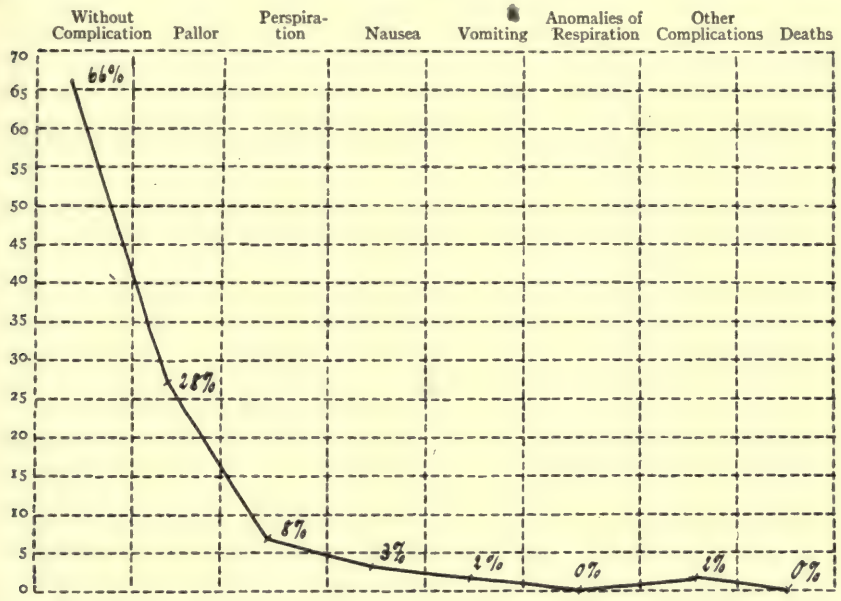

FIG. 345.—CHART SHOWING COMPLICATIONS IN 670 SUCCESSIVE ANESTHETIZATIONS. (Kroenig and Siegel.)

some form of inhalation anesthesia. The worst, however, that can happen is a partial success. Table IV (Kroenig) records the results obtained in 556 operations upon the abdomen and pelvis. It will be noted that the total duration of these 556 operations was 509 hours and 46 minutes, during which time the cavity was open 202 hours and 9 minutes. Eighty-five per cent were carried out without recourse to other anesthetics, and in the remaining 81 operations (15 per cent) a total of but 80 c.c. of ethyl chlorid, 63 c.c. of chloroform and 736 c.c. of ether were employed. The average duration of each operation was 55 minutes.

Sacral Extradural Anesthesia.—These terms imply the injection of an anesthetic solution into the extradural space within the sacral canal by way of the hiatus sacralis. It is a conduction, regional anesthesia by means of which the impulses of that system of sensory nerves supply-

TABLE IV (KROENIG AND SIEGEL)

Operations	Number	Duration in Minutes	Opening of Peritoneum Minutes	Ethyl Chlorid c.c.	Chloroform c.c.	Ether c.c.	With Inhalation in Addition	Without Inhalation in Addition
Groin incisions	105	3,595 minutes				63	11	95
Laparotomies and nephrectomies	306	18,792 minutes	11,431	45	55	636	60	246
Vaginal operations	145	8,199 minutes	698	35	8	37	10	135
Total	556	30,586 or 509 hours 46 minutes	12,129 or 202 hours 9 minutes	80	63	736	81	475

ing chiefly the anal region and genital organs are interrupted. To Cathalin is due the credit of having first drawn attention to this form of anesthesia. In 1903 he published his experiments on sacral injection, by which, using 3 c.c. of a 0.1 per cent solution of cocain, he was able to produce anesthesia of the entire body of a dog. His attempts to obtain like results in man did not, however, succeed. The method of Cathalin was tested by many surgeons with almost uniform failure until Stoeckel, using the relatively non-toxic novocain, succeeded in definitely reducing the severity of labor pains. Stoeckel's success was due almost entirely to the larger amounts, 30 c.c. of a 0.5 per cent solution, which he was enabled to inject by substituting the novocain.

For several succeeding years these injections were limited in their application almost entirely to the realm of obstetrics, and it was not until 1910 that the method was rendered practicable for surgical operations. At this time Läwen pointed out the necessity of employing only definite concentrations and definite quantities of novocain solution, namely 20 c.c. of a 1.5 to 2 per cent novocain solution. Läwen's formulae are in common use to-day and have been proved by repeated experience to be the most effective.

Sacral anaesthesia is applicable to operations on the anus, lower portion of the rectum, perineum, urethra, penis, prostate, vulva and vagina. While areas in the distribution of the sciatic and inferior gluteal nerves are often rendered analgesic, this is rarely, if ever, sufficient to permit of operative procedures upon these parts. It should also be remembered that the testicles being innervated from higher centers cannot be affected by sacral anesthesia.

Because of its low toxicity novocain is the anesthetic of choice. In preparing its solutions the observation of Gross that the chlorids of the anesthetic drugs combined with sodium bicarbonate act more powerfully, should be taken into account.

Läwen recommends the following combinations:

Solution I

Sodii bicarbonatis	0.15 gm.
Sodii chloridi	0.1 "
Novocaini	0.6 "

To be dissolved in 30 c.c. of distilled water. This gives a 2 per cent solution of novocain-sodium bicarbonate, of which 20 c.c. should be injected.

Solution II

Sodii bicarbonatis	0.2 gm.
Sodii chloridi	0.2 "
Novocaini	0.75 "

To be dissolved in 50 c.c. of distilled water. This yields a 1.5 per cent solution of which 20 to 25 c.c. may be injected.

The powder should be dissolved in distilled water. After solution is complete, the fluid is brought to the boiling point. This not only sterilizes the liquid, but increases its anesthetizing powers. When cooled, and immediately before injection, five drops of a 1-1,000 adrenalin chlorid solution are added to the amount to be injected.

It is best to employ a Record syringe of 20 c.c. capacity. The needle should be of the same length as that employed for spinal anesthesia and should be of iridoplatinum. Sufficient quantities of morphin or morphin-scopolamin should be given, as for the other forms of conduction anesthesia. No further preparation is necessary, other than the precautions detailed under paravertebral anesthesia. For procedures below the symphysis pubis, *low anesthesia,* the patient is placed on his side with knees flexed, and the site of injection disinfected with iodin. The needle is introduced in the center of a vertical line drawn from the apex of the sacral triangle to its base, a point corresponding to the hiatus sacralis. Skin anesthesia is induced by the intradermic injection of 0.5 per cent novocain solution. The long needle is now introduced down to and through the sacral membrane which covers the sacral canal. The needle at its introduction should be held at an angle of 45° with the skin surface. Puncture of the sacral membrane conveys the same impression to the hand of the operator as when the dura is traversed in lumbar puncture. The needle is now depressed until the angle of 45° is bisected. It now approximately parallels the canal along which it is slowly and gently insinuated, following the curves of the latter, until it has reached a depth of 6 cm., when the needle will have penetrated the canal a distance of 4 to 5 cm. The orifice of the needle is watched for a moment for escaping blood. If this occur, a sacral vein has been punctured, necessitating a change in the level of introduction. It is also well at this time to make a test injection of 10 c.c. of physiological salt solution. If the solution be easily injected and there be no subcutaneous swelling, the needle is in the proper position. The anesthetic solution is now slowly injected at an even rate. At least two minutes should be consumed for the actual injection. This tends to diminish the amount of anesthetic absorbed into the general circulation, while it permits of the more gradual and even distribution of the fluid throughout the loose areolar tissue occupying the canal and surrounding the nerves. Slow introduction also permits of the fluid remaining in the lower part of the epidural space. Should any untoward symptoms arise, such as disturbance of pulse or respiration, the injection should be immediately stopped. The solution already injected cannot be recovered. As a rule the maximum anesthesia is attained in about twenty minutes, but the time taken for its action varies from ten to twenty-five minutes. Anesthesia is first observed between the coccyx and the posterior border of the anus and from this point it spreads over the perineum and skin of the scrotum to the penis and glans, extending

upward to the symphysis pubis and downward into the gluteal region. The urethra, vulva, vagina and vaginal portion of the cervix, with at times the prostate, will be found anesthetic. The duration is very variable, although, according to Läwen, it may last from one and one-half to two hours.

The technic of *high extradural anesthesia* differs somewhat from that of low extradural anesthesia. If instead of the horizontal position the

FIG. 346.—TECHNIC FOR SACRAL ANESTHESIA.
Position of patient and introduction of needle for sacral anesthesia.

patient be placed in the knee-chest posture (Fig. 346) during and for two or three minutes following the injection of the anesthetic into the sacral canal, higher diffusion of the fluid within the epidural space will occur with a resulting higher level of anesthesia. This method has been studied chiefly by Schlimpert and Schneider. Extension of anesthesia to the umbilicus, sometimes to the breast, and even to the lower border of the second rib, has been observed. This form of anesthesia is, however, too dangerous and not to be recommended and has been largely supplanted by the spinal or paraspinal methods.

As a rule the accessory reactions after low extradural anesthesia are neither severe nor dangerous, provided proper technic be observed and the solutions be not too concentrated. Rapid absorption by too rapid injec-

tion or injection directly into a vein, are dangers to be borne in mind. Acceleration of the pulse, giddiness, vomiting and at times collapse may occur, and exceptionally respiratory disturbances. On the whole, sacral anesthesia offers no advantages over the parasacral or paravertebral methods and is more dangerous.

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CHAPTER XV

LAMINECTOMY

For purposes of exploration, for the treatment of injuries to the spine or cord, or of inflammatory lesions of the spinal canal and its contents, such as lues, actinomycosis and tuberculosis, for the removal of tumors and cysts, and for operations upon the sensory or posterior roots, the spinal canal must be exposed by the removal of the spinous processes and laminae of one or more vertebrae. With the introduction of this operation, laminectomy so-called, as an orderly and useful procedure, we associate the name of Macewen. To master the technic of laminectomy requires less experience and training than that of opening the cranial chamber; the mere mechanics of exposing and removing the spines and arches is easily acquired. To be sure, the proper instruments should be at hand, the patient must be in the proper position and attention must be paid to numberless details, but the important step of the operation, both from the standpoint of the patient's life and of the accomplishment of that for which the operation is undertaken, is not reached until the dural sac is opened and the cord and roots laid bare. From this point the operation is more or less intricate, of minor or major gravity, precisely in proportion to how much or how little the cord and roots are disturbed before the dural sac is closed. Just as too much emphasis has been laid upon the mechanics of craniotomy *per se* and too little upon the obligations and demands upon the surgeon after the skull is opened, so too much emphasis has been laid upon the most effective way of reaching the spinal canal and too little upon what is fundamental to success in intraspinal procedures after the dural sac is opened.

Preliminary Preparation.—While the skin of the back is coarse and thick with many sebaceous glands and hair follicles, conditions which would seem to make thorough disinfection more difficult, I know of no region where asepsis is so readily and so constantly maintained as in that of the laminectomy incision. There is, therefore, no necessity for any modification of the methods of skin preparation appropriate for other parts of the body, and in my clinic we rely implicitly upon benzin and iodin.

The presence of decubitus, especially if near the site of the incision, is somewhat disconcerting and demands additional precautions. In the days preceding the operation special attention should be paid to the ulcers and every means adopted to control the infection. To this end the ulcer should be treated two or more times a day, according to the profuseness

of the exudate, and its surface cleansed with peroxid of hydrogen and swabbed with tincture of iodin (3.5 per cent) and the surrounding skin cleansed with alcohol. At the time of the operation a protective dressing is applied and hermetically sealed with strips of adhesive plaster. Thus, throughout the operation the field is adequately protected, provided the incision does not come in such close proximity to the periphery of the decubitus as to be directly contaminated even by the lymphatics that may be charged with microörganisms.

FIG. 347.—POSITION OF THE PATIENT ON THE OPERATING TABLE FOR EXPLORATION IN CERVICOTHORACIC REGION.

For adequate exposure of this region a suitable head rest is necessary in order that the head and neck may be properly flexed. The apparatus attached to this table is capable of adjustment in any direction or angle.

The **operating table equipment** and the **position of the patient** are of no little importance. The operating table is constructed so that it may be in the reversed Trendelenburg position and at any angle up to 45°. Attached to the table is a head-rest, designed by my former assistant, Dr. L. H. Landon, equipped with ball and socket joint so that the head and neck may be flexed or arched, as is desirable in operations on the cervical vertebrae. This to all intents is the same position as prescribed for suboccipital craniectomy (Fig. 347). Both in the thoracic and tho-

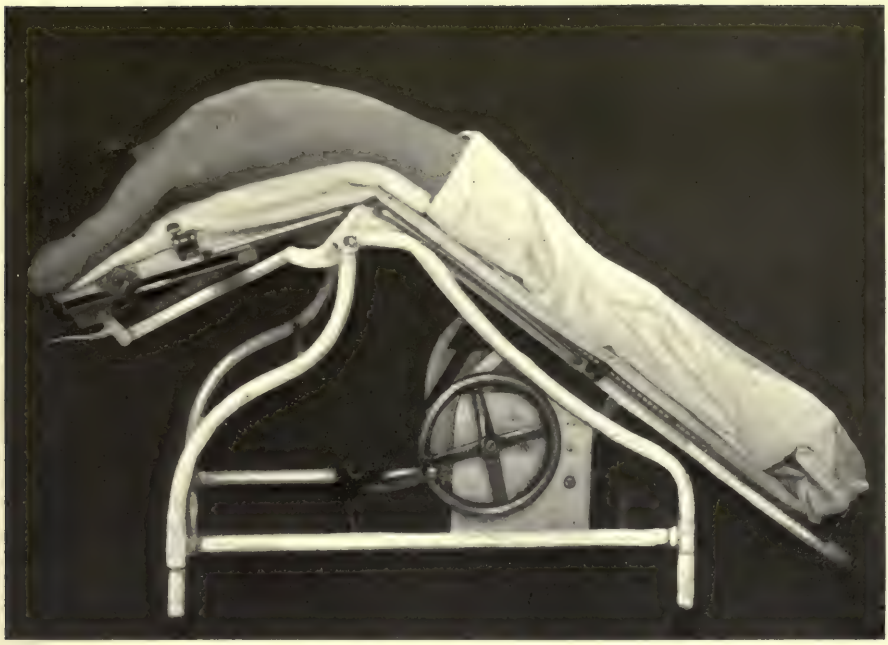


FIG. 348.—POSITION OF PATIENT ON THE OPERATING TABLE FOR EXPLORATION IN THORACIC REGION.

The table is adjusted so that the mid-thoracic region is at the highest level of the dural sac.

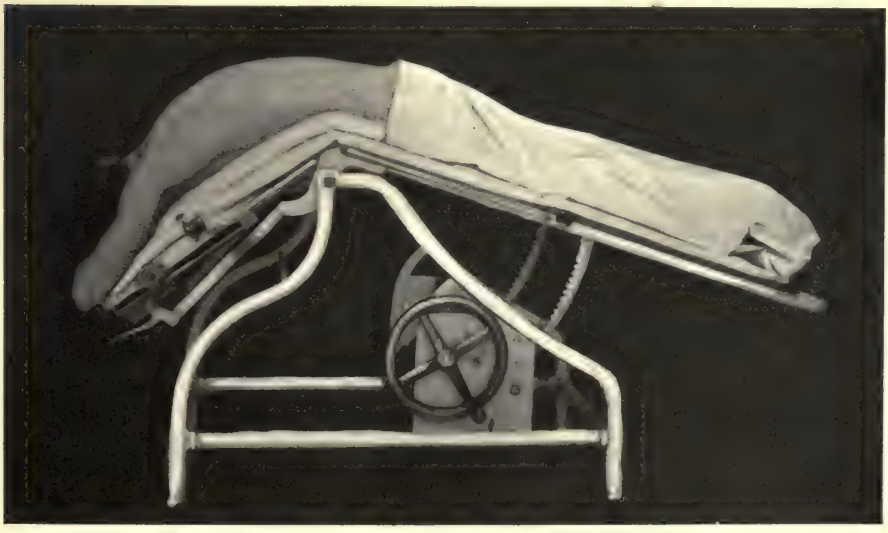


FIG. 349.—POSITION OF THE PATIENT ON THE OPERATING TABLE FOR EXPLORATION IN LUMBAR REGION.

By lowering both the head and foot of the table, the lumbar region is at the highest level of the dural sac.

racicolumbar region the spine should be arched, so as to separate as far as possible the spines and laminae from one another. In the upper thoracic region, this is accomplished by lowering the head and shoulders above and the pelvis and legs below (Fig. 348), and in the thoracicolumbar by placing an air cushion under the patient at the level of the opening. Whenever possible, it is desirable to have the head and shoulders on a lower level than the dural opening in order to control by gravity the escape of cerebrospinal fluid from the subarachnoid space of the cranial cavity (Fig. 349). Inasmuch as endotracheal anesthesia is employed in all my spinal cases, the possible embarrassment of respiration by the prone position, even when respiration is already embarrassed by paralysis of the intercostal muscles, is a matter of no moment.

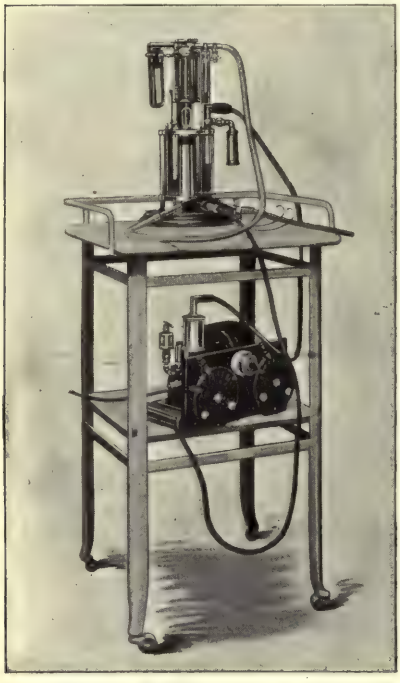


FIG. 350.—ENDOTRACHEAL ANESTHESIA APPARATUS DESIGNED FOR AUTHOR'S CLINIC BY DR. GEORGE P. MÜLLER.

Anesthesia.—In most instances the operation is carried out under *general anesthesia,* although occasions have arisen when I have thought a general anesthetic might be undesirable, and under such circumstances, referred to below, I have been able to complete the operation under local anesthesia. With these exceptions ether is used in my clinic and administered by the endotracheal insufflation method of Meltzer. The apparatus (Fig. 350) designed by my associate, Dr. George P. Müller, has proved in every respect satisfactory; it is less complicated and less expensive than many others on the market. The tube is introduced with the Jackson laryngoscope, and after the patient has been placed on the operating table, no concern need be given to the patient's position, except as above noted, other than to avoid pressure of the neck upon the upper edge of the table. Endotracheal insufflation anesthesia has very peculiar advantages in spinal operations. As the term implies, anesthesia is maintained by ventilation of the lungs with ether vapor under a regulated pressure. The ventilation of the lungs is effectively accomplished entirely without the assistance of the act of respiration, and oxygenation of the blood is adequately maintained. Whether respiration be embarrassed by paralysis of the intercostal or abdominal muscles, as it sometimes is in spinal lesions, or by the

prone position of the patient on the table, the insufflation of the lungs with air, charged with ether, by the endotracheal apparatus, is quite sufficient not only to maintain an even anesthesia, but to oxygenate the blood adequately throughout the operation. For these reasons the use of the apparatus is strongly to be recommended not only as a matter of convenience but as a means of increasing the margin of safety.

Local Anesthesia.—Under certain conditions, notably when the patient's vitality is greatly exhausted by the disease and when, as in trauma of the lower cervical cord, with paralysis of the intercostal and abdominal muscles, there is the greater risk of pneumonia, I have resorted to local anesthesia. The skin and musculo-aponeurotic layers are readily rendered anesthetic by the infiltration of 0.5 per cent novocain, and while it might be possible to anesthetize the periosteum of spines and laminae, though not so effectively, when the time comes to remove these I use nitrous oxid-oxygen anesthesia. Novocain infiltration of the cutaneous and muscular layers, with nitrous oxid-oxygen anesthesia for the skeletal work, has proved a very happy combination and may be considered an important factor in minimizing risks in desperate cases. The patient is given hypodermatically morphin sulphate 0.01 gm. and atropin sulphate 0.0016 gm. one-half hour before the operation; the skin along the projected incision is infiltrated with 0.5 per cent novocain solution, and after the skin flaps are reflected on either side, the aponeurosis and the muscles down to the spines and laminae are infiltrated with massive doses of the same solution. For one operation 250 c.c. may be required. When the spines and laminae are exposed, nitrous oxid-oxygen is given and continued until the bone

FIG. 351.—DRAWING SHOWING THE DISTRIBUTION OF THE CUTANEOUS RAMI FROM THE POSTERIOR PRIMARY DIVISIONS OF THE SPINAL NERVES.

These rami supply the structures in the territory of a laminectomy.

work is completed. The spinal dura is more sensitive than the cranial dura, and, before it is incised, either it must be injected with novocain or the nitrous oxid-oxygen continued.

While this method has proved satisfactory in a number of cases, I have been impressed with the greater effectiveness of regional anesthesia, especially in operations upon the thoracic region. The sensory supply of the structures in the field of operation is derived from the cutaneous rami of the posterior primary divisions of the spinal nerves (Fig. 351; see also Figs. 262, 263). Following the technic for alcoholic injection of the intercostal nerves (*vide* p. 635), as many nerves on either side as may be necessary, according to the number of laminae to be removed, are injected with 0.5 per cent novocain solution. It may be necessary to supplement these primary injections with injections directly in the line of incision and subperiosteally on either side of the laminae. By a combination of these injections, I have been able to open the spinal canal for various lesions without the aid of a general anesthetic.

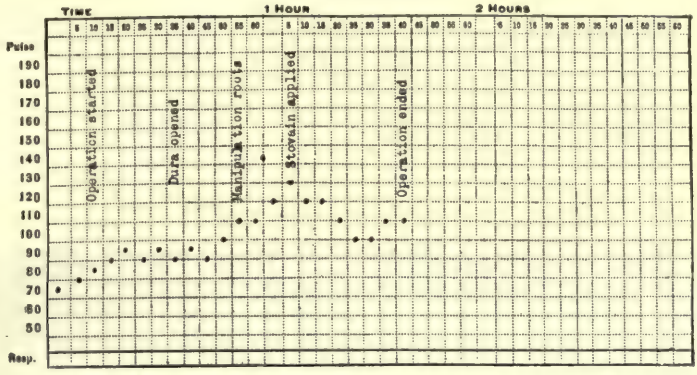
One- or Two-Stage Operation.—The question of a one- or two-stage operation is often the subject of discussion, but I do not believe in an attempt to settle it, either *pro* or *con,* in an arbitrary manner. Each case is a law unto itself, but the decision rests with the judgment of the operator. I depend almost altogether upon the blood pressure as the most valuable index to the patient's condition. If the blood pressure be maintained at an approximately normal line in the preliminary stage of exposure, there is no reason whatsoever for discontinuing the operation until a second stage. And the more attention one pays to the control of hemorrhage and the avoidance of unnecessary trauma, the less frequently will the operator be forced, as a measure of safety, to postpone the completion of the operation until a second stage. As a matter of fact, I have had to resort to the two-stage operation but twice. The pulse rate and blood pressure are recorded on a special chart (Fig. 352) at five-minute intervals by an assistant, and a glance at the chart, constantly within view of the operator, serves to keep him accurately and continually informed as to his patient's condition.

Instruments.—The mechanics of removing the spines and laminae are comparatively simple and few instruments are required. Each operator may determine for himself the instruments with which he can remove the spines and laminae with greatest facility and with the least expenditure of time or infliction of damage. While a great variety of instruments has been suggested and recommended, I have found a modification of the Liston forceps for the removal of the spinous processes and rongeur forceps of various sizes and angles for the removal of the laminae meet every requirement. As with all operations upon the skeleton, the bone-cutting instruments should be sharpened before every operation. Some

ANESTHESIA AND BLOOD PRESSURE RECORD.

NAME HOSPITAL INDEX FILE NO. VOL.

ANESTHESIA CHART.



Operation Laminectomy Date 12-4-15 Operator Frazier

Operation Started 9:10 a. m. Operation Ended 10:45 a. m.

Anesthetic Ether

Variety Squibbs Method Endotracheal Anesthetizer Miss Bellis

Time to Anesthetize 15 minutes Amt. to Anesthetize Total Amt. Used 5 ounces

Examination of Chest (before) Negative

BLOOD PRESSURE CHART.

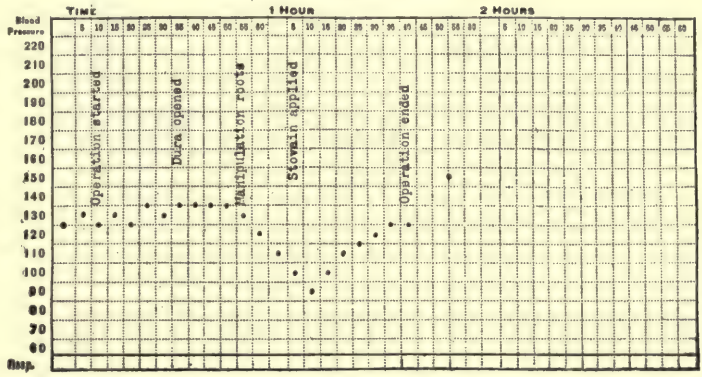


FIG. 352.—COMBINED ANESTHESIA AND BLOOD PRESSURE CHART ON WHICH ARE NOTED THE VARIATIONS IN THE PULSE RATE AND BLOOD PRESSURE AT DIFFERENT STAGES OF THE OPERATION.

Note the increase in pulse rate and fall in blood pressure when the roots are manipulated incidental to their division, also the beneficial effect of the stovain block upon the blood pressure and pulse.

surgeons employ saws for the laminae, such as the Gigli saw, Horsley's saw or Doyen's circular saw, others again the conical trephine, and while these may prove satisfactory in the hands of those who use them, the

selection of one instrument or another must be considered as matters of personal preference.

In addition to the bone-cutting instruments, but few instruments appropriate especially for spinal operations are required in the armamentarium. Among these may be mentioned two pairs of self-retaining retractors with curved teeth (Fig. 353) which are particularly helpful in that they maintain an even and constant retraction of the muscles throughout the operation and, at the same time, release an assistant's hands for other duties. Horsley's wax is required to control bleeding from the cut sections of laminae. Mosquito forceps may be required after the dura is opened, and for cutting the theca or roots a pair of iris scissors. For the separation or isolation of roots and sometimes for retraction of the

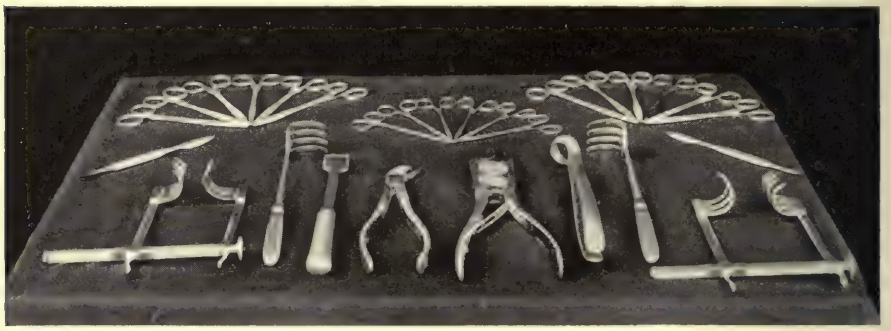


FIG. 353.—SPECIAL INSTRUMENTS USED IN LAMINECTOMY.

cord I have used hooks of glass instead of metal. These serve a twofold purpose: being fragile, they serve as a constant reminder to operator or assistant of the obligation to employ the minimum amount of traction force, and as they are non-conductors, they do not transmit to an adjacent root or to the cord the electric current that we may be using for identification of individual roots. In the closure of the wound several kinds of needles should be available: for the dura, a small cutting edge, curved iris needle; for the splint sutures, a full curved Hagedorn needle; for the muscles or fascia, an Emmet needle; and for the skin a straight Hagedorn needle. The suture material includes arterial silk, iodin catgut and silkworm gut.

Localization.—In preparation for all intraspinal operations, excluding those for trauma, but more particularly for resection of the roots, some means should be adopted for accurate localization of at least one spinous process. This is best accomplished by selecting for identification the spinous process about the middle of the contemplated laminectomy. Using the seventh cervical or vertebra prominens as a starting point in the cervicothoracic region, or the last thoracic in the thoracicolumbar region, we count the successive spines until the desired one is reached and

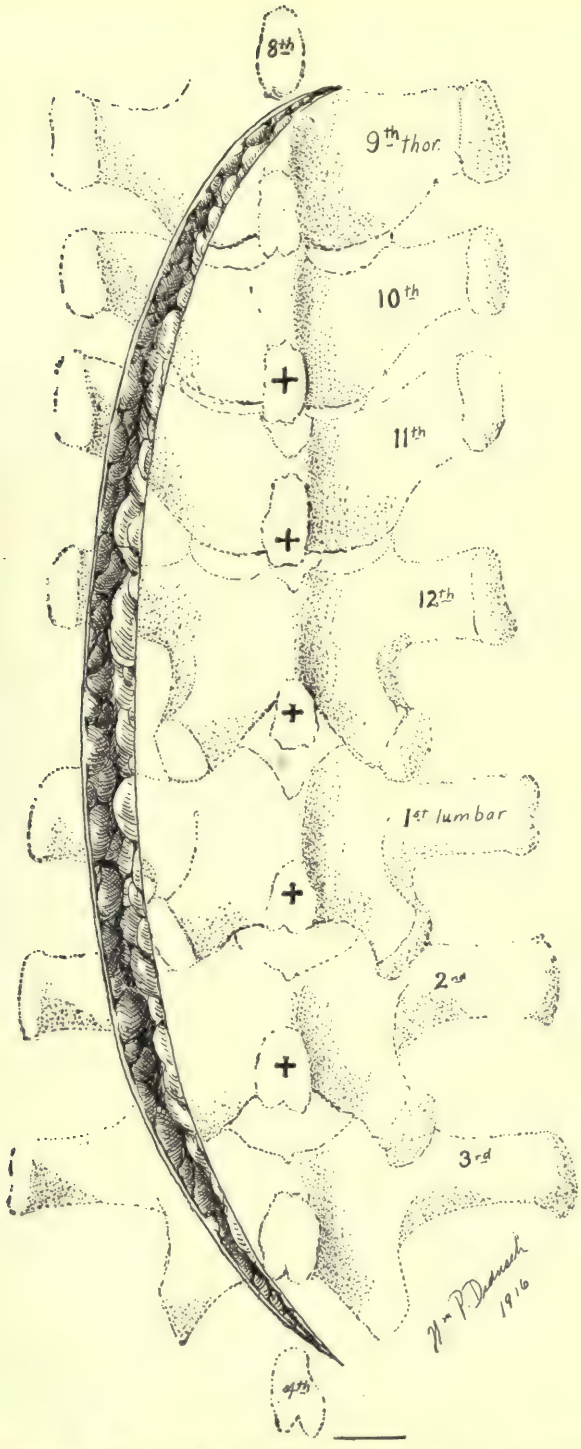


FIG. 354.—LENGTH AND RELATION OF THE SEMILUNAR INCISION IN THE SKIN TO THE SPINOUS PROCESSES FOR A LAMINECTOMY TO INCLUDE THE TENTH, ELEVENTH, AND TWELFTH THORACIC AND FIRST AND SECOND LUMBAR VERTEBRAE.

FIG. 355.—TECHNIC OF LAMINECTOMY.

The cutaneous flap is reflected, showing the oval incision in the intervertebral fascia beginning one spinous process above and one below the contemplated opening in the spinal canal.

marked with an aniline pencil. A strip of metal is fastened to the skin at this level and a roentgenogram made. The latter will determine whether the first calculation is correct, for, as often happens, the identified spinous process is one above or below. The identification of a given spinous process having thus been confirmed, the overlying skin is indelibly marked with caustic silver.

The Operation.—With this preliminary preparation, with the patient's position properly adjusted, skin disinfected, and the field of operation surrounded with sterile sheets, the operation begins. The incision is semilunar in shape so that upon reflection of the flap adequate exposure is afforded of the structures beneath (Fig. 354). The incision proportionate to the predetermined number of laminae to be removed should be long enough to include at least one spinous process above and below the contemplated opening, since it so often happens that one additional lamina above or below may have to be removed. This initial incision extends to the level of the intervertebral fascia. The margins of the flap, including the skin and subcutaneous tissue, are then covered with cloths as a means of protecting the deeper structures from skin contamination.

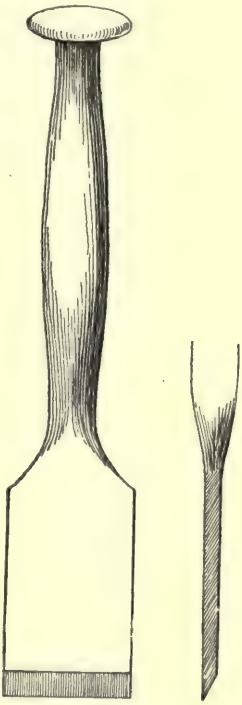


FIG. 356. — BROAD-BLADED CHISEL FOR SEPARATION OF THE MUSCLES FROM THE SPINOUS PROCESSES IN LAMINECTOMY.

The incision in the intervertebral fascia begins in the median line at the tip of the spine above the first spine to be removed, and following closely the lateral aspects of the spines, first on one, then on the other side, terminates in the median line just below the last spine to be included in the laminectomy (Fig. 355). The incision in the intervertebral fascia is made with a heavy knife and should penetrate the muscular sheath. The separation of the muscular layer from either side of the spines and from the laminae may be done rapidly with a broad chisel (Figs. 356, 357 and 358). By some it has been said that a subperiosteal separation of muscles from the spines may be made, and while this is to be desired as a means of lessening hemorrhage, it is difficult, if not impossible, to remove the periosteum intact. However, an effort should be made to keep the chisel as close to the bone as possible and, if feasible, at certain points beneath the periosteum. The preservation of the periosteal layer, partially at least, makes possible more or less bone regeneration so that the defect consequent upon the removal of the spines may be in part repaired. In fact, complete bony arches, replacing the original laminae, have been found at secondary operations.

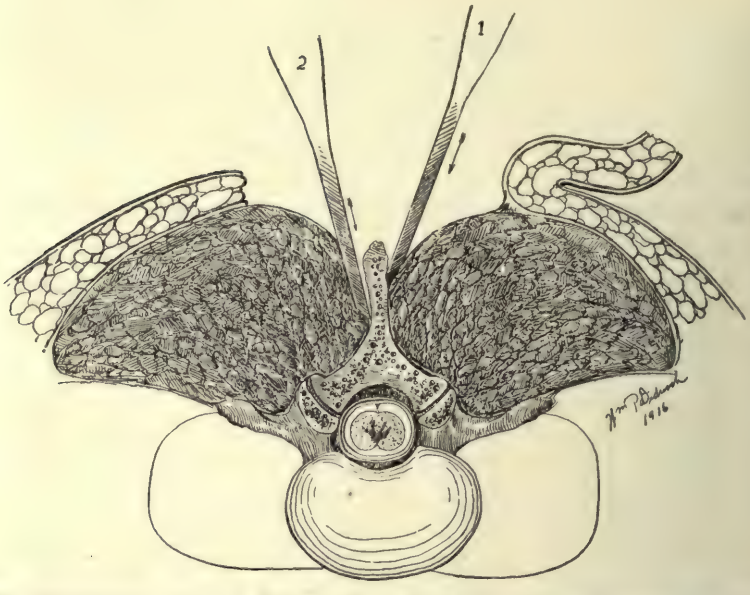


FIG. 357.—SEPARATION OF THE MUSCLES FROM THE TIP OF THE SPINOUS PROCESS IN LAMINECTOMY.

At this stage of the operation there will be more or less bleeding; more if the chisel penetrate the muscles, less if it hug closely to the spines, but hemorrhage is readily controlled by tamponing the wound at once with compresses wrung out in hot normal salt solution. Upon separation

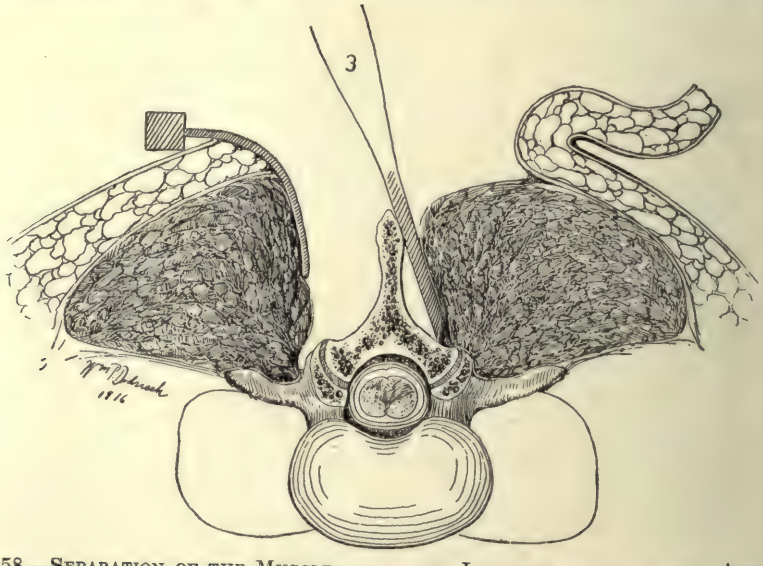


FIG. 358.—SEPARATION OF THE MUSCLES FROM THE LAMINAE AS FAR AS THE ARTICULAR PROCESSES, IN THE OPERATION OF LAMINECTOMY.

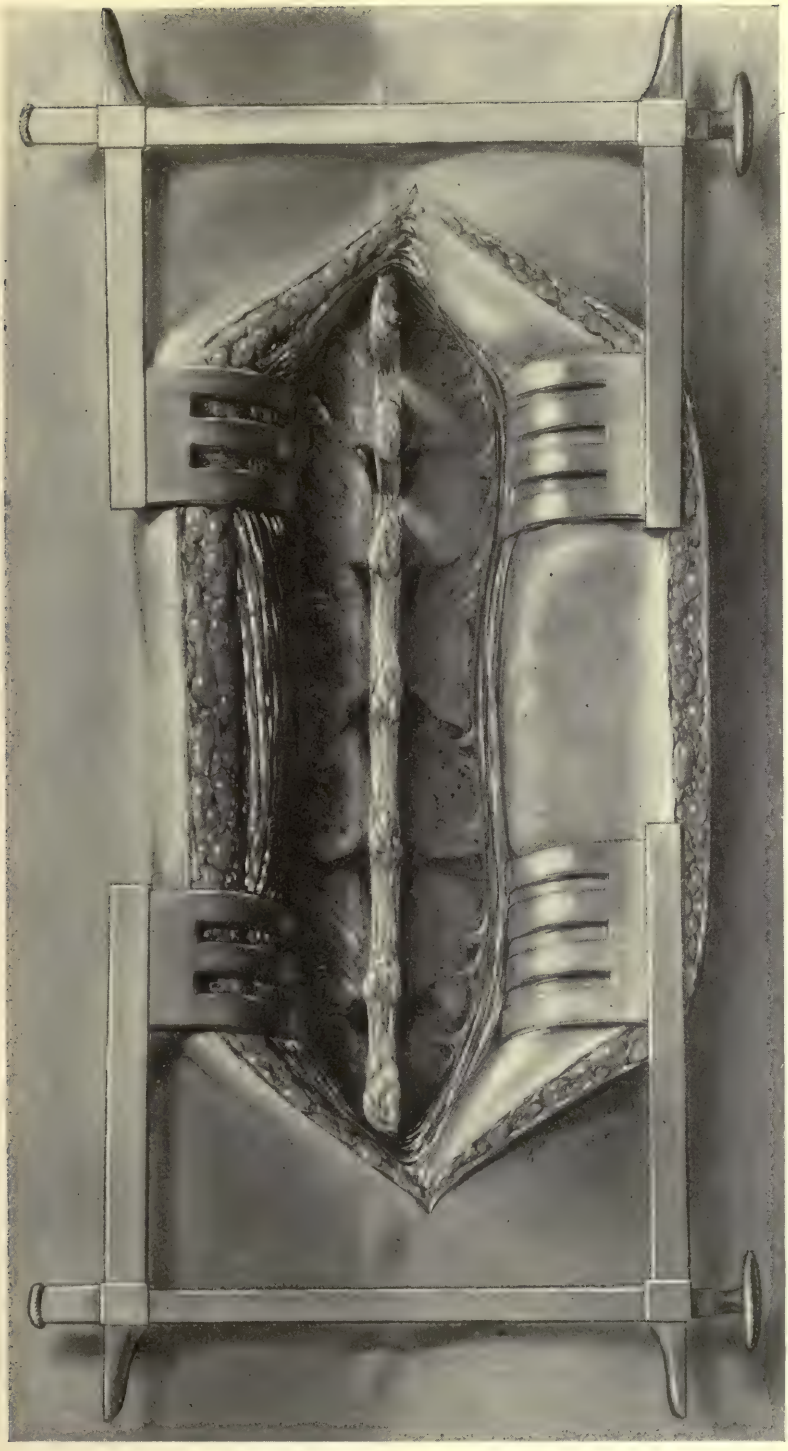


FIG. 359.—TECHNIC OF LAMINECTOMY.
Two pairs of self-retaining retractors introduced one at the upper and one at the lower angle of the wound.

of the muscle layer on one side the wound is tamponed before proceeding with the other side, or even before the muscles have been separated from the laminae below. Thus, by working first on one side, then on the other, complete separation of the muscles from spines and laminae is effected with a minimum amount of bleeding, and by the time this has been accomplished and the tampons removed, hemorrhage is well under control. It may be necessary to ligate several bleeding points in the belly of the

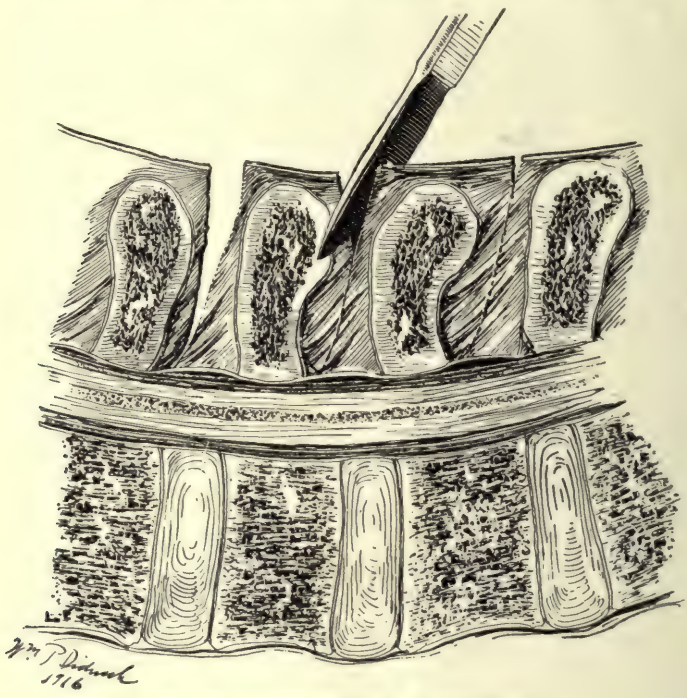


FIG. 360.—TECHNIC OF LAMINECTOMY.
Division of the interspinous ligaments.

muscle or in the sheaths and aponeurosis, at which level the largest blood vessels will be found. Intramuscular injections of adrenalin solution, as recommended by some, are unnecessary.

The self-retaining retractors are now introduced, one or two pairs, according to the length of the wound, and beneath them, covering the exposed muscle surface, are spread gauze pads (Fig. 359). The blades of the retractors are separated sufficiently to bring into view the articular processes on either side. The ligamenta interspinalia having been divided with a heavy bladed knife above and below (Fig. 360), the several spinous processes are removed one by one with bone-cutting pliers and the corresponding laminae with rongeur forceps (Figs. 361 and 362). In removal of the laminae an opening is made with a small pair of forceps or, as

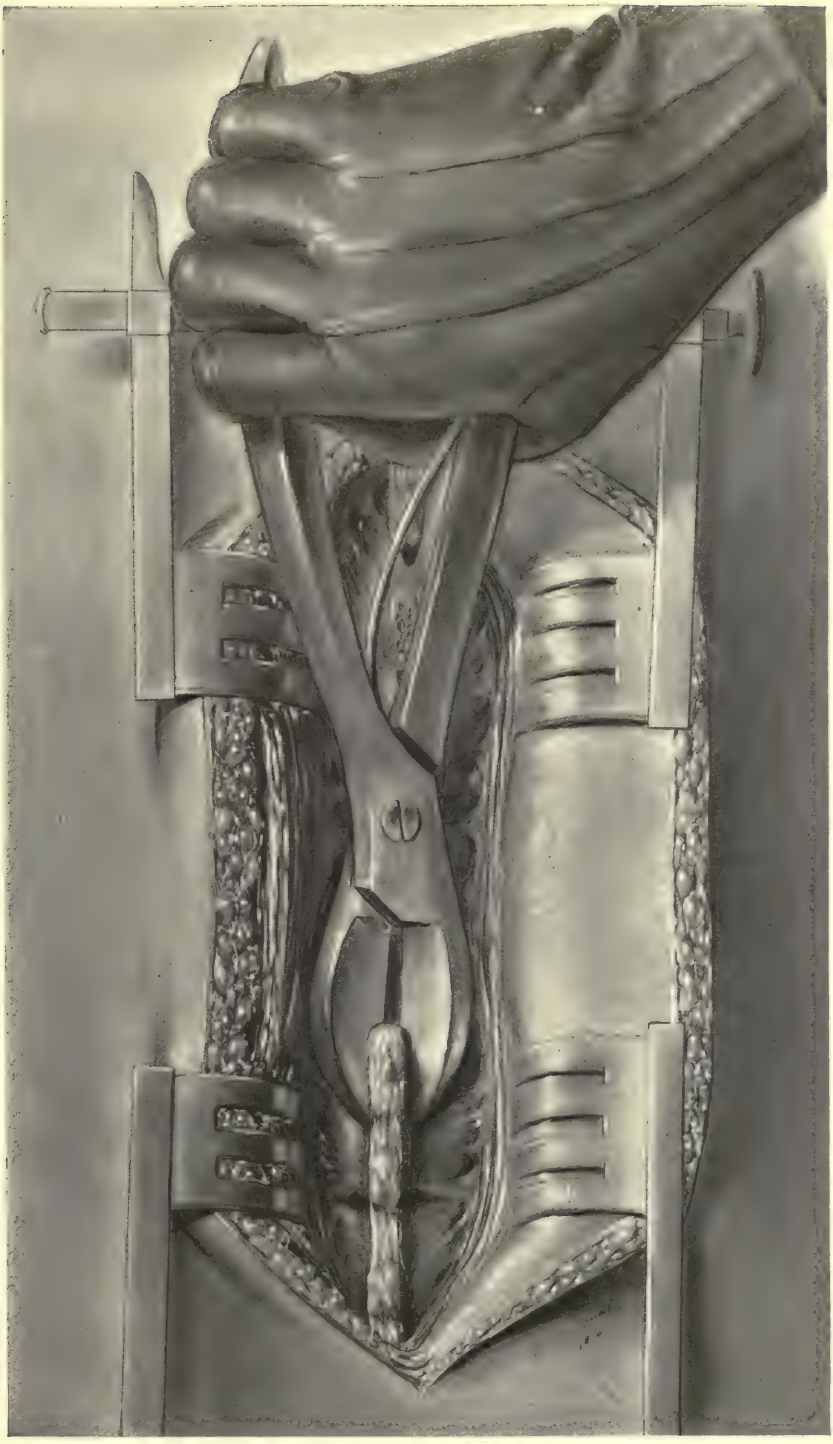


FIG. 361.—TECHNIC OF LAMINECTOMY.
Removal of the spinous processes.

in the lumbar region, with a drill, and as soon as the space is large enough, the heavy forceps are substituted and the several arches to either side as far as the articular processes, if necessary for proper exposure are quickly removed piecemeal (Fig. 363). While the cord is protected throughout the spinal canal by the epidural fat and in the lumbar region by the ligamenta subflava, care must be taken to avoid injuring the cord in the removal of the laminae. This is especially true in cases of marked kyphosis, where the dura is in closer contact with the arches and in fracture-

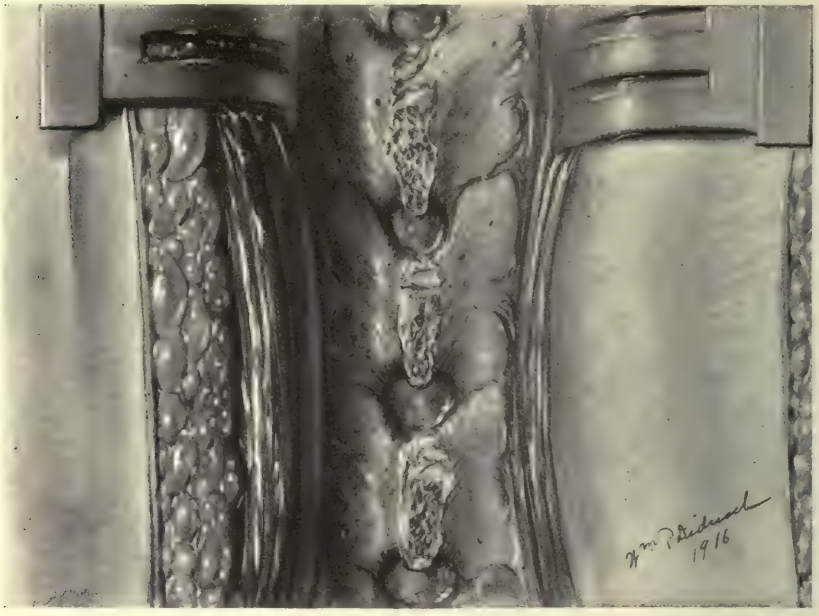


FIG. 362.—TECHNIC OF LAMINECTOMY.
Exposure of the vertebral column after the spinous processes have been removed.

dislocations where the cord may be compressed by the displaced vertebrae. The removal of spines and laminae is accomplished with more or less facility, according to whether the operation is in the cervical, thoracic, or lumbar region. In the cervical region both spines and laminae are of relatively light structure, but as one passes down the spine these skeletal processes increase in size until in the lumbar vertebrae they reach their maximum. The task of removing many laminae in the lower spine is not calculated to prepare the operator for the more delicate manipulations to follow. His hands may become cramped and his coördination less adaptable, so that I have found it a good plan to relegate this task in part at least to a trained assistant.

The osteoplastic method is a complicated procedure and the theoretical advantages are more than overbalanced by the disadvantages. All that

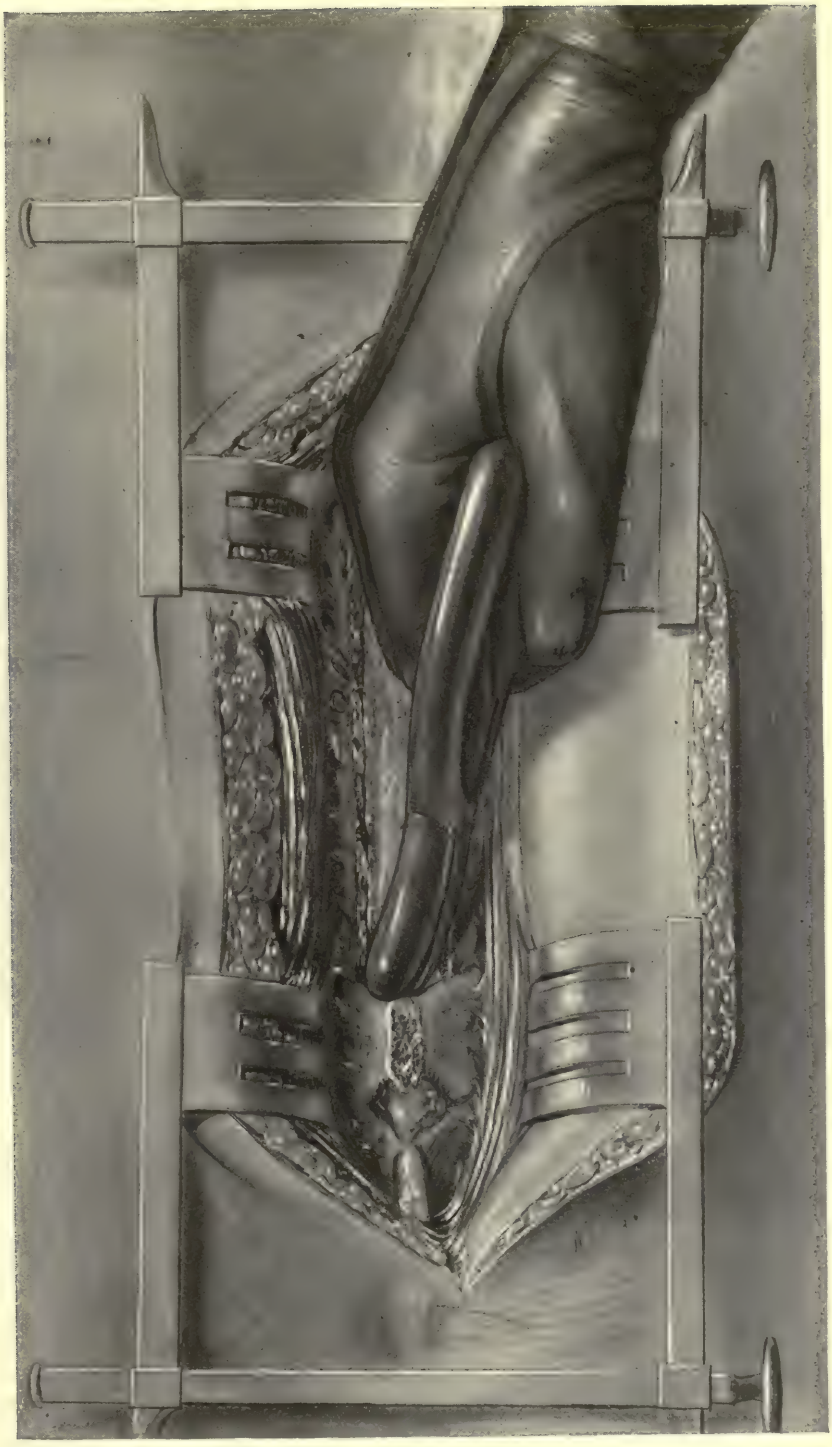


FIG. 363.—TECHNIC OF LAMINECTOMY.
Removal of the laminae.

can be said in its favor is that the restoration of the laminae will better conserve the strength and function of the spinal column, and yet experience has amply demonstrated that good functional results follow even very extensive laminectomies. The osteoplastic method is much more difficult of execution, prolongs the operation, and has its chief objection in the complications that occur when the necessity arises, as it so often does, to extending the exploration either above or below the original exposure.

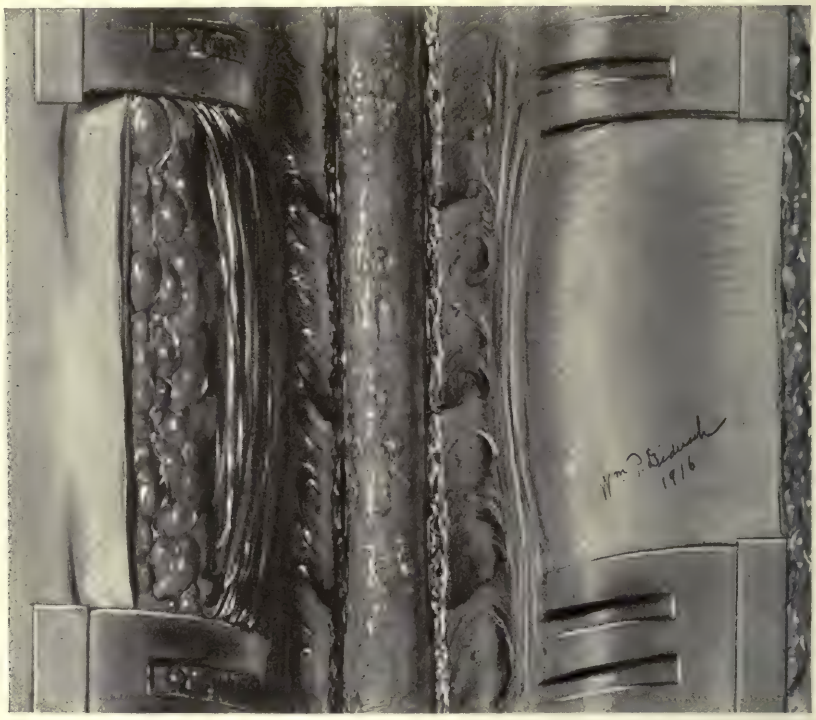


FIG. 364.—TECHNIC OF LAMINECTOMY.
Exposure of the cord after the removal of the laminae.

Once the laminectomy is completed (Fig. 364) and before the dura is opened, the operator surveys the field in search of bleeding points. Hemorrhage from every source should be under control before the dural sac is entered, and to this end the operator will avail himself of one means or another, according to the source of bleeding. If from the bone, sterile wax is the most effective, and if from other structures, heat in the form of tampons wrung out in hot saline solution, tampons of cotton or small pieces of muscle tissue, will usually meet every contingency.

The subsequent steps of the operation will depend upon whether the lesion is extradural or intradural. Before opening the dura at least a careful inspection should be made for extradural processes, possibly a

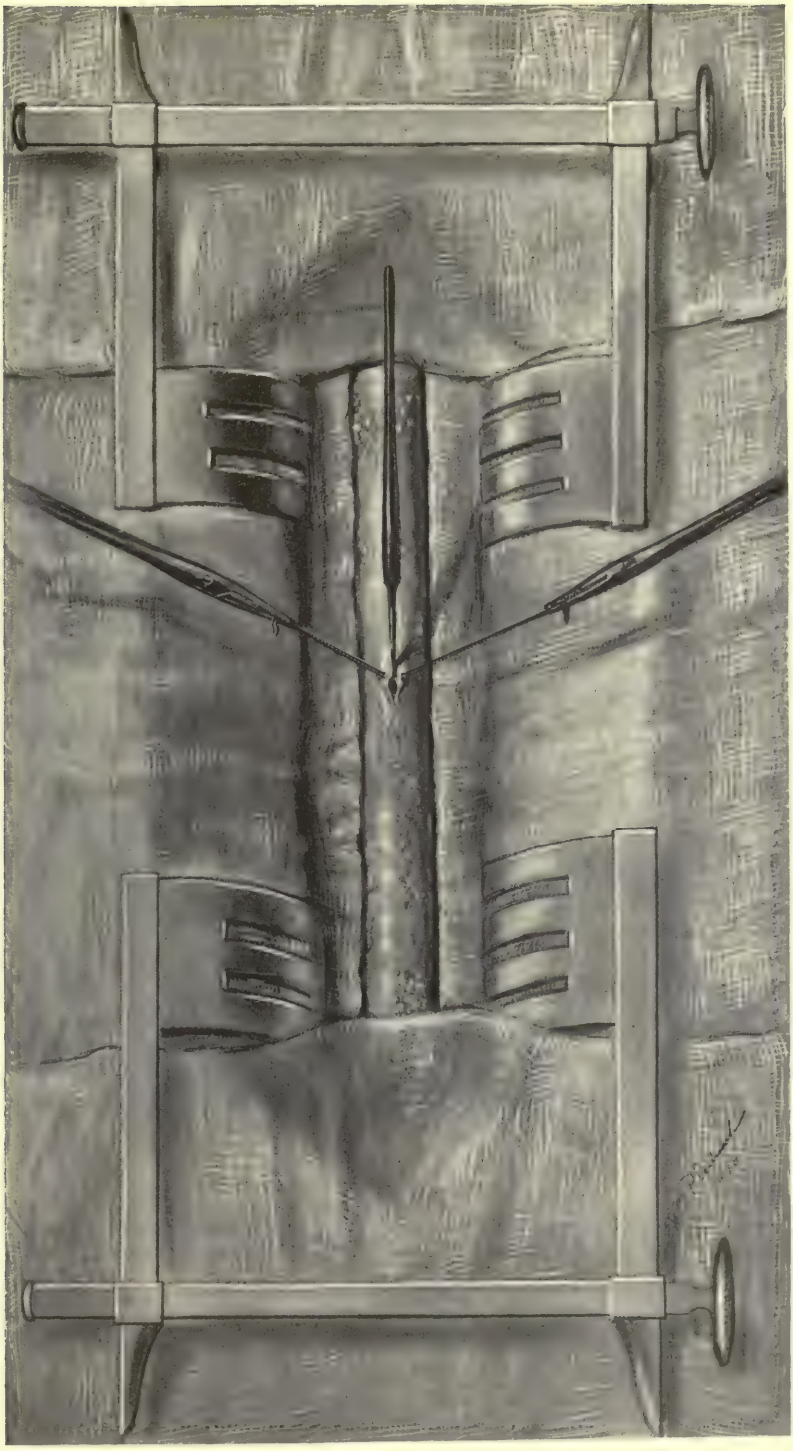


FIG. 365.—TECHNIC OF LAMINECTOMY.

The general appearance of the operative field before the dura is opened. The musculocutaneous structures down to the level of the dura are entirely covered with gauze pads. Traction sutures have been introduced in but not through the dura as the incision in the dura is begun.

tumor, a deformity following fracture, tuberculous foci or what not, and the lesion found to be extradural, further exposure is obviated. It would be especially undesirable to invade the subarachnoid space and expose the spinal membranes or cord to infection, should the process prove to be tuberculous. A fusiform swelling of the dural sac, if present, suggests an intradural lesion and gives a clew as to its location.

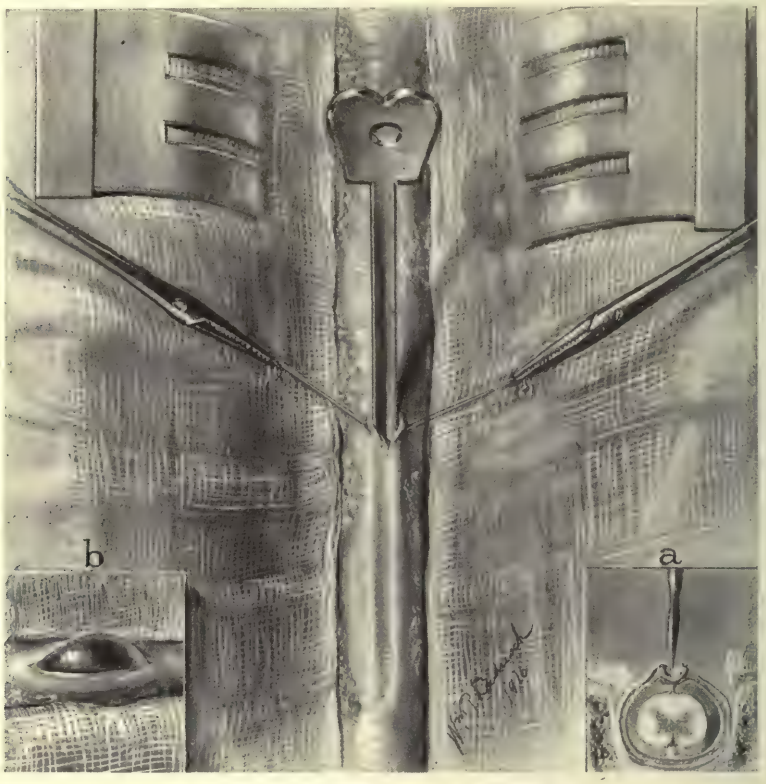


FIG. 366.—TECHNIC OF LAMINECTOMY.

The introduction of the grooved director through the initial opening in the dura. *a*, the knife in place in the groove of the director as the dural incision is made. *b*, the thin filmy arachnoid membrane ballooning through the dural incision.

Before the dura is exposed to view the thin layer of fat, together with the plexus of veins, must be displaced to either side. A careful inspection of the dura at this stage may bring to light the nature of the lesion. Under normal circumstances the dura is of a bluish-white color and about the thickness of the dural covering of the brain. Discoloration of the dura with or without the presence of granulation tissue bespeaks an inflammatory process. The absence of pulsation is, of course, most suggestive of a tumor, although both the arrest of pulsation and the oval swelling may be caused by a circumscribed pachymeningitis. To

open the dura introduce two silk traction sutures, one on either side of the median line, mounted on small curved needles, which enter the dura but do not penetrate it. Slight traction upon these sutures frees the dura, and between these a minute incision is made with a small scalpel down to but

Fig. 367.—Technic of Laminectomy.

After the three pairs of traction sutures have been introduced, a roll of cotton is laid in the trough on either side of the dural flap to absorb the blood which may gravitate to the bottom of the wound, and to prevent its entrance within the dural sac. *a*, cross section representing the relation of the cotton roll to the dural sac.

not including the arachnoid (Fig. 365). The latter lies in such close apposition to the dura that in some cases even with care the scalpel will puncture it and the cerebrospinal fluid gush forth. But if not perforated, the arachnoid will balloon through the dural incision under the pressure of the

pent-up fluid. The dural incision is lengthened by cutting over a director first in one direction, then in another (Fig. 366). Before incising the arachnoid, four additional traction sutures are introduced through the margin of the dura—two above and two below those already in place. The three pairs of traction sutures are grasped separately with mosquito forceps,

FIG. 368.—TECHNIC OF LAMINECTOMY.
The appearance of the operative field after the dural flaps have been reflected with traction sutures.

which by their weight alone will retract the dural flaps sufficiently to afford ample inspection of the subarachnoid space. But before retracting the flaps a roll of cotton a centimeter in diameter and the length of the dural incision is laid in the bed of the wound to the outer side of each dural flap (Fig. 367). These cotton rolls will absorb the blood that may

gravitate to the bottom of the wound during the operation and prevent its entering the subarachnoid space. If at any time they become saturated, fresh ones should be substituted. While perfect hemostasis is unquestionably a *desideratum,* in the strictest interpretation this is not feasible, and yet it is entirely possible to prevent leakage into the subarachnoid space. For this reason the cotton roll plays a very important rôle.

The operator pauses now to inspect the field (Fig. 368), and with the arachnoid still intact, his observations may give a clew to the seat and character of the lesion. Under normal circumstances the cerebrospinal fluid pulsates synchronously with the pulse and with respiration. In many instances the respiratory movements may be seen when the pulsations are not visible. This natural phenomenon may not be present if the subarachnoid space above the opening be so obstructed that free communication above is interrupted. In addition to the presence or absence of pulsation, the operator informs himself as to the degree of tension of the cerebrospinal fluid, and as to whether the cerebrospinal fluid is excessive; he notes whether the excess of fluid is evenly distributed or circumscribed as in circumscribed serous meningitis. In the case of intradural tumor an excess of fluid is found usually above the tumor, though occasionally below, but in either case the fluid may be under such tension that not the slightest pulsation can be detected. Once the subarachnoid space is open the cerebrospinal fluid escapes under varying degrees of tension. Through the initial puncture of the arachnoid I have seen the fluid spurt into the operator's face.

The sudden escape of cerebrospinal fluid has been charged with many offenses by many surgeons. There seems to be a deeply rooted conviction that the escape of fluid is responsible for sudden changes in pulse rate or blood pressure, responsible for respiratory embarrassment; in fact, for all that goes to make up the picture of shock. These untoward effects are attributed to the sudden change of pressure and its harmful influence upon the circulation of the medullary centers. I have always taken the position that the escape of cerebrospinal fluid was incorrectly charged with the symptoms of "spinal shock," as it has been called. Rather are these the consequence of the surgeon's disregard of certain elementary principles as prophylactic of shock, chief among which I place hemorrhage and trauma. The importance of hemostasis and its means of accomplishment have been discussed, so that it suffices at this time to call attention to them merely by way of emphasis. The second important injunction, the avoidance of trauma, applies, of course, only to the steps of the operation that have to do with the spinal membranes, the roots and the cord. Unfortunately, the preliminary work in muscle and bone cannot be accomplished with that respect for the tissue that is possible only with sharp dissection. The blunt removal of muscle from bone, the chipping away of spines and arches, are at best crude, but once the bone work is completed

and the dural sac invaded, there must be a complete transformation of procedure from one that is gross in the extreme to one that is refined and delicate. It becomes the surgeon to avoid all traumatizing influences, whether chemical, thermal, or mechanical, among the latter being included undue traction upon the dura, undue traction either directly or indirectly upon the roots, unnecessary sponging and all unnecessary manipulation of cord or roots. I have been convinced of the evil effects of trauma by many operative experiences, particularly those upon the roots. Not until it becomes necessary to manipulate the roots, as in separating the anterior from the posterior, will any material change be noted on the pulse or blood pressure. Unfortunately, the character of the lesion or operation demands at least some disturbance of the cord or roots, so that its ill effects cannot be altogether avoided, but they can be minimized in two ways: first by delicacy of manipulation, as though the operator were handling the most delicate glass, and secondly, by the stovain block (*vide* chapter on Rhizotomy, p. 749). The application of a pledget of cotton, saturated with 1 c.c. of 4 per cent stovain, to the cord and roots at the site of manipulation or just above it has a positive inhibitive influence.

While I do not believe the sudden escape of cerebrospinal fluid is the cause of spinal shock, I can readily see how undesirable it would be to allow the dural sac, ventricles and cisterns to be emptied of their fluid contents during operation. The continued flow of fluid is prevented partly by arching the patient's back so that the opening in the dura is at the highest level of the subarachnoid space; but to keep the field entirely dry, posture must be supplemented with small tampons of cotton gently introduced between cord and dura just above and below the upper and lower limits of the dural incision. With this preparation the operator is prepared to inspect the meninges, roots and cord, and the subsequent steps of the operation will depend upon the nature of the lesion.

Closure of the Wound.—Before closing the dural wound hemorrhage must be under absolute control. The presence of even a small amount of blood with its fibrin content leads inevitably to the development of adhesions, and though this may not lead to serious consequences, every effort should be made to avoid them and to leave the structures within the sac as nearly free from the effects of trauma as possible. But a freer hemorrhage within the sac is responsible unquestionably for some of the functional disturbances, either transitory or permanent, that have followed laminectomies. The presence of complete or partial paralysis of one or both extremities, or of bladder or rectum, may be the result of trauma incidental to traction upon the cord or roots or possibly to the resulting edema, following exploratory laminectomies, but the persistence of these motor phenomena should be charged in most instances to hemorrhage. Perfect hemostasis is, therefore, a *sine qua non* in preparation for closure of the dura. There are occasions when with propriety the

dural incision may be left unsutured. Pachymeningitis hypertrophica cervicalis chronica and inoperable tumors are conditions in which for the relief of pressure it is advisable not to suture the dura, and in meningitis serosa chronica there are some who believe in the advantages of providing

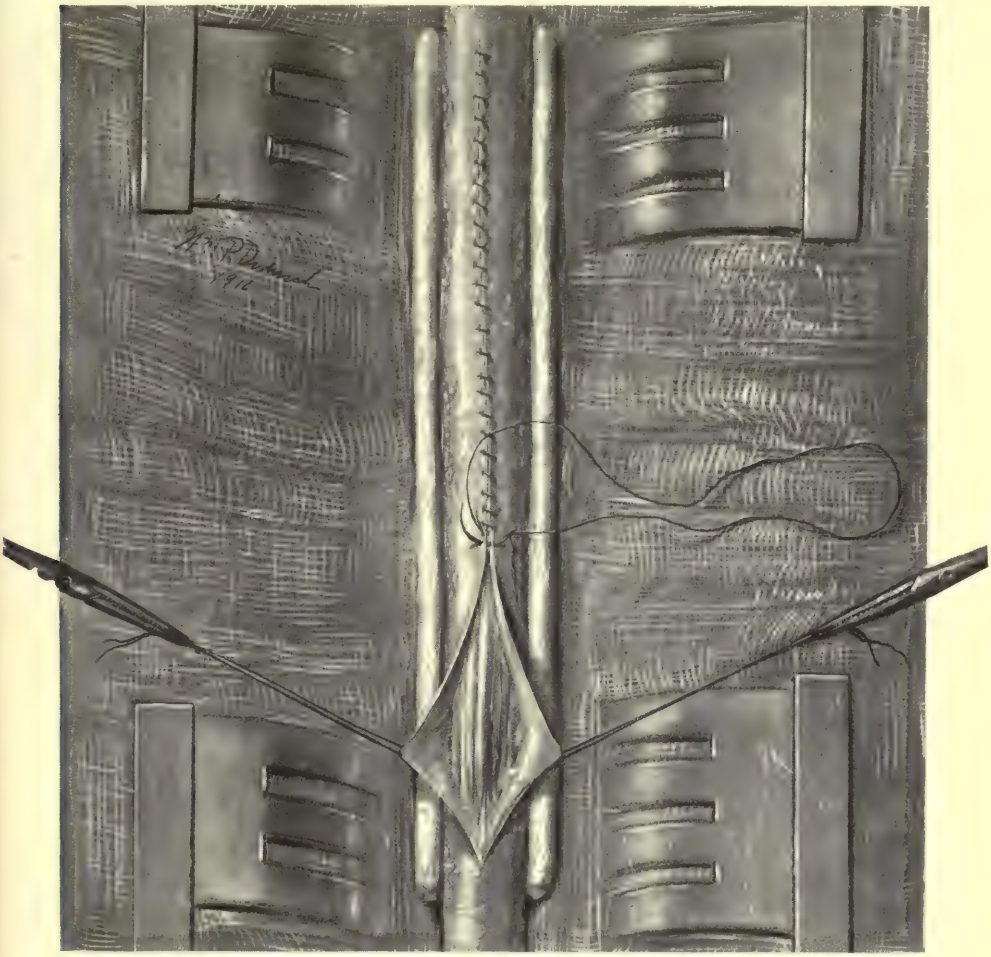


FIG. 369.—TECHNIC OF LAMINECTOMY.
Closure of the dural incision with continuous silk sutures.

for drainage, thus preventing the reaccumulation of cerebrospinal fluid. With this view, however, I am not in accord.

To close the dural incision a small, curved iris needle and 00 silk should be used. A continuous suture is preferable to an interrupted suture as a safeguard against leakage and the establishment of a cerebrospinal fistula (Fig. 369). The needle is introduced precisely in the edge of the dural incision, the suture is continuous, and with the wound

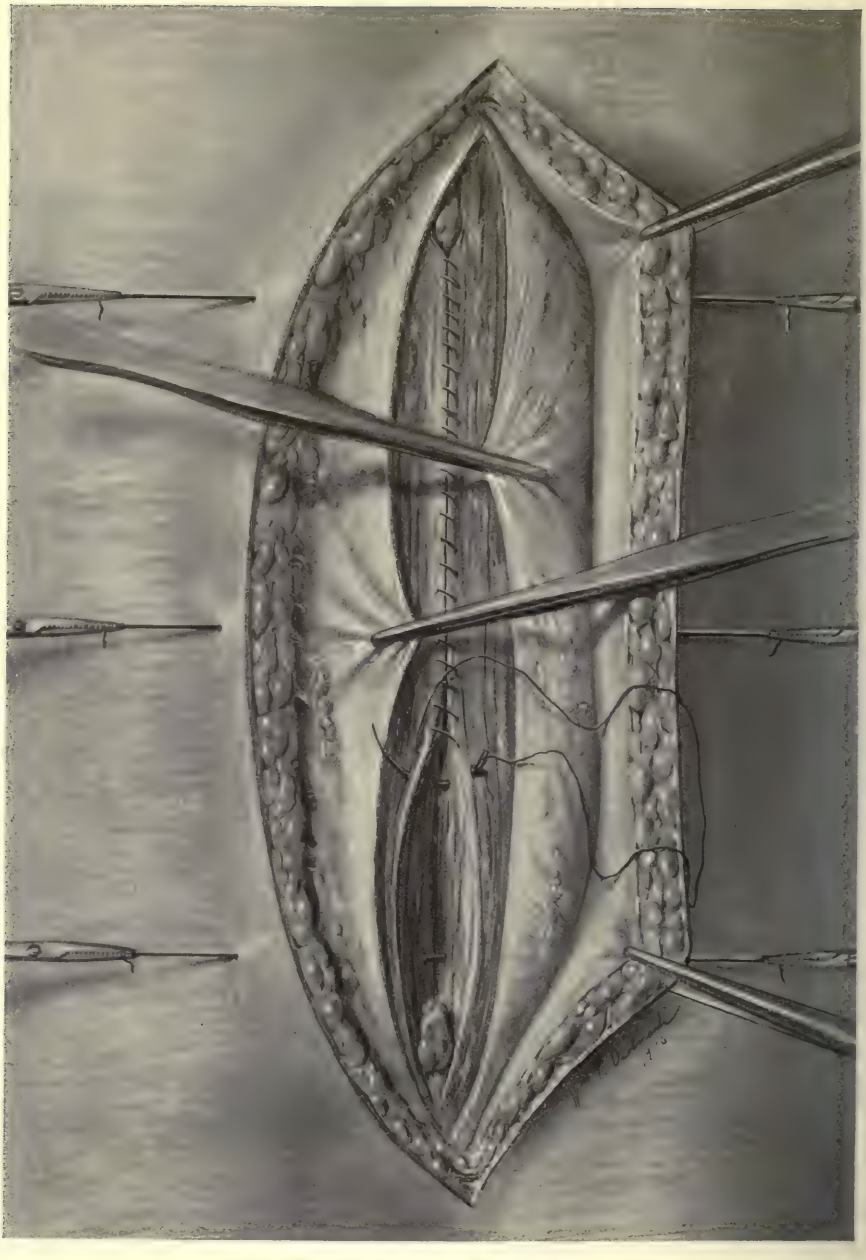


FIG. 370.—TECHNIC OF LAMINECTOMY.
Continuous catgut suture which penetrates only the muscle sheath. On either side of the incision may be seen the ends of the splint sutures clamped with hemostats.

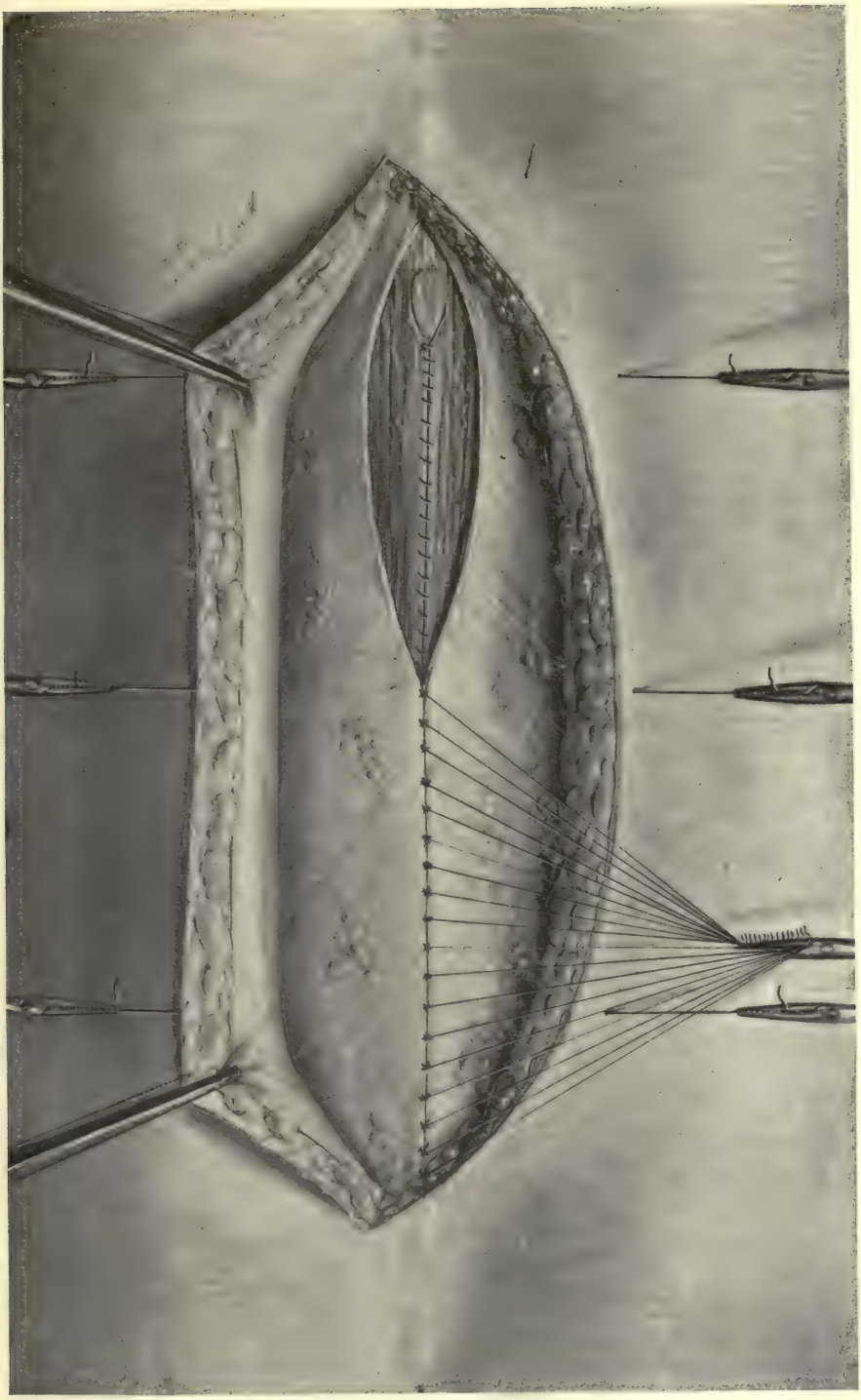


FIG. 371.—TECHNIC OF LAMINECTOMY.
Interrupted catgut sutures in the intervertebral fascia.

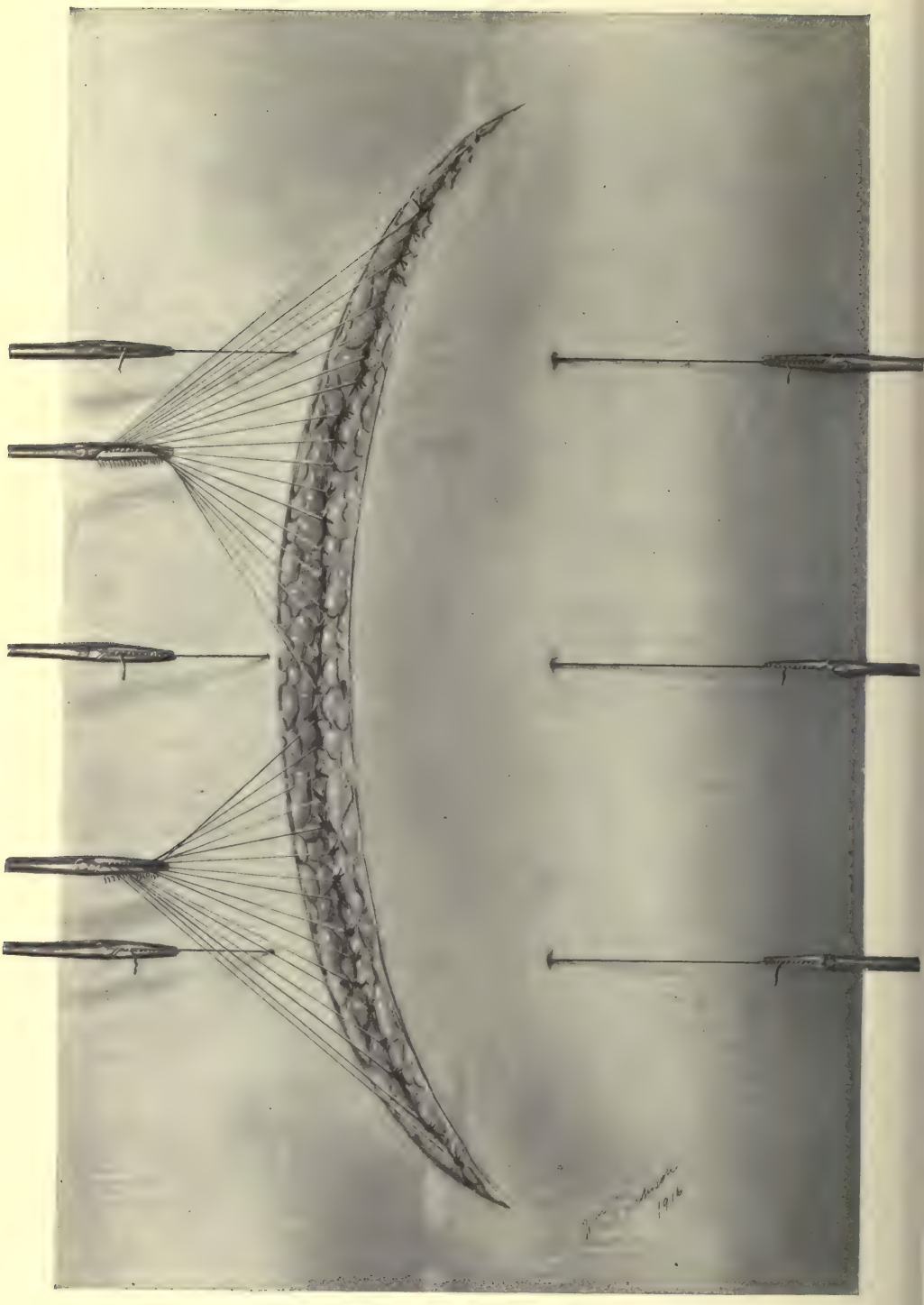


FIG. 372.—TECHNIC OF LAMINECTOMY.
Closure of the superficial fascia with interrupted catgut sutures; the splint sutures remain untied.

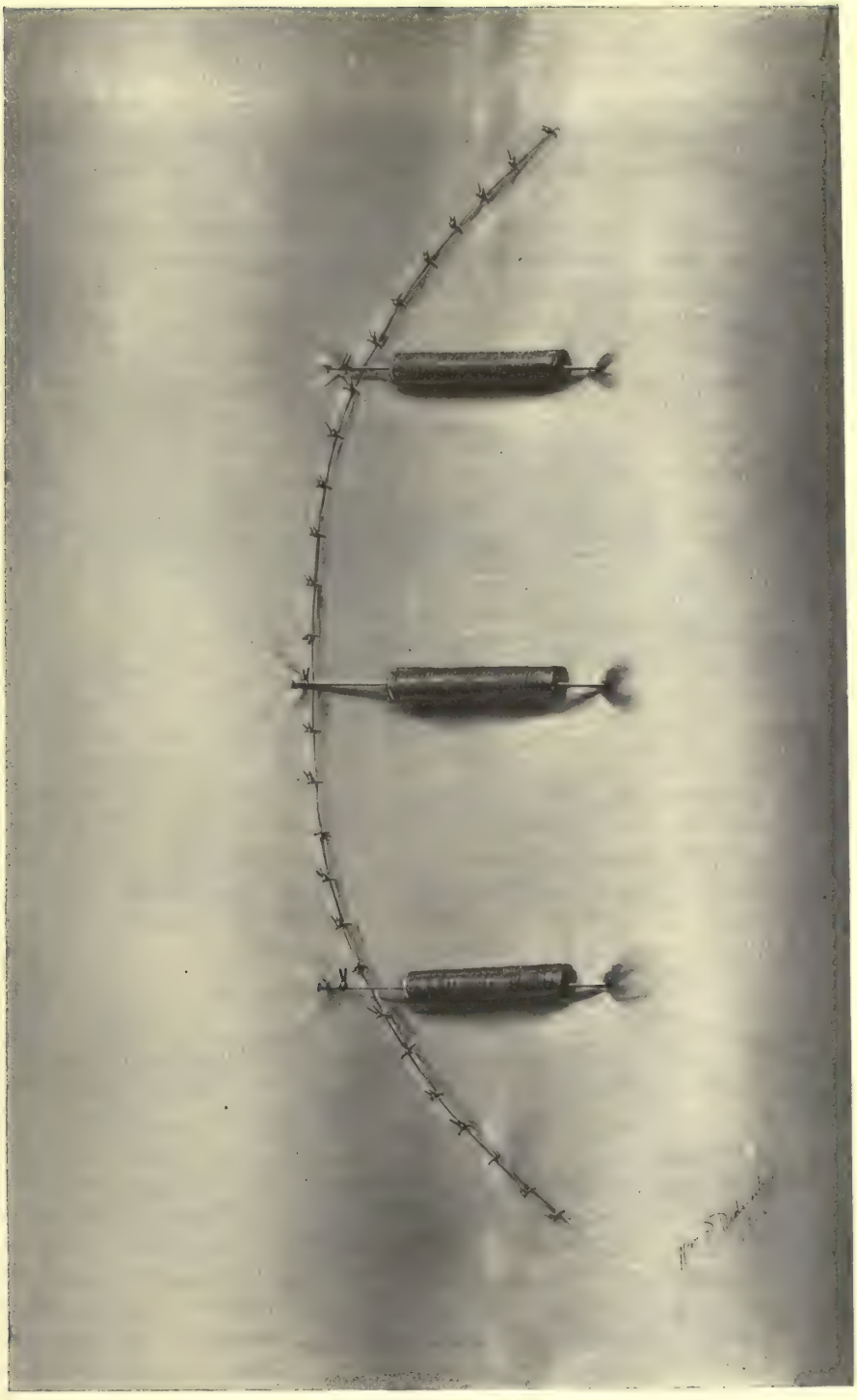


FIG. 373.—TECHNIC OF LAMINECTOMY.

Appearance of the wound after the cutaneous interrupted sutures have been introduced and the splint sutures, armed with rubber tubing, tied.

thus closed, no foreign material will be exposed within the dural sac and there can be no leakage through the needle punctures and no leakage along the line of suture. When these details are observed in the technic of dural suture, I have never seen any escape of cerebrospinal fluid after laminectomies.

To obliterate the "dead space" that remains after removal of the spinous processes and laminae, three or four splint sutures, according to the length of the incision, are introduced at this point, through the erector spinalis, intervertebral and superficial fascia and skin, and left untied until the wound is closed. A row of sutures of continuous iodin catgut brings the sheath and margins of the erector spinalis into apposition

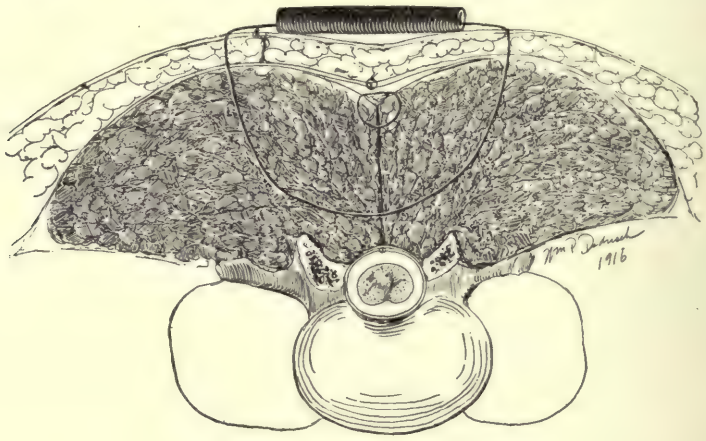


FIG. 374.—TECHNIC OF LAMINECTOMY.
A cross section of the wound, showing the effect of the splint sutures in the obliteration of the intramuscular space.

(Fig. 370), and over this the intervertebral fascia is brought into apposition with interrupted sutures of catgut (Fig. 371). The intervertebral fascia is a strong unyielding structure and unquestionably plays an important part in preventing such incapacity as might come from the removal of the spines and interspinal ligaments. As giving support to the structures of the back after laminectomies, it plays a part analogous to that of the fascia of the external oblique after operations in the lower abdomen. There remain to be closed, the skin and the superficial fascia, which are brought into apposition separately, the latter, with interrupted catgut sutures (Fig. 372) and the former with sutures of interrupted silkworm gut (Fig. 373). After closure of all the layers of the wound is completed, one end of the splint sutures is threaded through a section of narrow rubber tubing and the sutures tied, the rubber tubing preventing the sutures from cutting through the skin (Fig. 374). The skin is again disinfected with iodin and the dressing applied (Figs. 373 and 374).

After the Operation.—The management of the patient after a laminectomy must take into consideration various conditions that do not pertain to operations elsewhere. With decubitus already present, or from the nature of the lesion likely to develop, the patient is placed upon a water or air mattress. On the bed immediately beneath the dressing I place a square of wax paper covered with sterile cotton to absorb any blood that may ooze through. This is merely a precautionary measure. I have never had occasion to use fixation dressings, either of plaster of Paris or poroplastic felt. There is no indication for fixation, except perhaps in the cervical region, where the use of small sand bags on either side of the head and a strip of adhesive plaster from one to the other, crossing the patient's forehead, meets every need.

When the operation has been in the lumbar region the nurses and attendants should be warned of the risks of contamination of the dressings with the excreta, and as a protection, the dressing should be hermetically sealed around the edges as well as over the surface with adhesive plaster. With an incontinent bladder either a suprapubic drain or a permanent catheter is installed and retained at least until the wound is healed. The wound itself requires little attention; save for the removal of a drain at the end of twenty-four hours the dressing is not disturbed until the seventh day for the removal of stitches, at which time a protective pad is applied and allowed to remain until no further protection is required.

Tales of calamities from the escape of cerebrospinal fluid after laminectomies are more or less of a hoax. When the dural wound is closed, as I have directed, with a continuous silk suture properly introduced, no cerebrospinal fluid will escape, and I might even go so far as to say that even when I have had to remove a portion of the dura, I have had no apprehension of a cerebrospinal fistula, since the closure of the musculocutaneous wound with four tier sutures, one each in the muscles, aponeurosis, superficial fascia and skin, is an absolute guarantee against leakage. Where cerebrospinal fistulae have been established there is, of course, the danger of infection, and the convalescence will be embarrassed with intense headache and vomiting, sweating, hyperpyrexia and acceleration of pulse. In some cases it is reported the fistula closed spontaneously, in some the patient died of meningitis. To arrest the flow and to favor spontaneous closure, the foot of the bed should be elevated and, as a guard against infection, the wound should be cared for most scrupulously.

The condition of the patient after the operation is frequently not such as to give alarm. The pulse may be accelerated, the temperature subnormal and the skin leaky, but it is unusual to see the patient in a condition even of surgical shock or collapse. In the majority of cases, therefore, with the exception of morphin for the relief of pain, little or no medication is required, and because the sphincters are frequently para-

lyzed and because the dressing may become soiled by leakage, proctoclysis is not to be employed.

The most constant and often the only subjective disturbance is pain. Whatever may be the experience of others, I find that most of my patients have enough pain to require one or more hypodermics of morphin during the first twenty-four hours. The degree of pain will depend somewhat upon the nature of the operation, chiefly upon incidental trauma of the roots. So that after rhizotomy or the disentangling of a tumor from the roots, pain will be intense and morphin or codein is given just as liberally and frequently as may be necessary to ensure the patient's comfort. The effect of morphin upon the pulse rate under these circumstances is striking, so that morphin is just as clearly indicated as the employment of general cardiac stimulants is uncalled for.

No general rule can be laid down as to the period of enforced rest in bed. The extent of the laminectomy, whether in the cervical, thoracic or lumbar region, must be taken into account. In a limited resection, as of three or four cervical or thoracic vertebrae, I allow the patient to sit up at the end of the second week, but after more extensive laminectomies, especially in the lower thoracic and thoracicolumbar regions, the patient is content to remain in bed two weeks longer. In so many instances the patient is already paralyzed before the operation, that the question of his becoming ambulant depends more upon the paralysis than upon how many laminae were removed.

Complications.—The complications peculiar to laminectomy are chiefly those which arise from intentional or unintentional, avoidable or unavoidable, damage to the cord and roots, that is, motor or sensory disturbance, transitory or permanent. In the removal of tumors, the displacement of the cord or separation of roots involves a degree of trauma that may give rise to temporary disturbances of function, more often motor than sensory. Thus, there may be complete or partial paralysis of one or both lower limbs and of bladder and rectum, abdominal distention and anesthesia below the level of the operation. Although distention is a more frequent complication of operation upon the lower thoracic vertebrae, the abdomen becomes distended, sometimes to such a degree as to cause more or less respiratory embarrassment from pressure of the distended bowel upon the diaphragm. When, coupled with this, peristalsis is arrested and the patient is unable to pass gas, the condition presents a picture not unlike that of peritonitis minus tenderness. Fortunately, the distention is of short duration, disappearing gradually in two or three days, and unless the patient be in distress, the condition may be allowed to pass untreated. In the more exaggerated forms I have found the use of the rectal tube and 1 c.c. of pituitrin hypodermatically injected offered the greatest measure of relief.

After laminectomies there may be either retention or incontinence.

Retention of urine is really quite common, irrespective of what may have been the condition of the bladder before the operation, and restoration of bladder function may be a matter of days or weeks. When of short duration, intermittent rather than permanent catheterization is preferable, but, if after a few days there is no tendency to immediate restoration of function, permanent catheterization cannot be avoided. One cannot always rely upon the patient's sensations, as in certain regions, especially the lumbosacral, the patient is unconscious of the sense of overdistention. Incontinence of urine is a very much more grave complication, and implies more serious damage to cord or meninges. Whether it will be permanent or transitory may usually be determined by the nature and seat of the lesion. I have seen a number of cases of transitory retention, but only one instance of permanent incontinence.

Paralyses of bladder, rectum, or extremities, developing as complications after operations within the dural sac, wholly irrespective of what might have been due to the lesion, are unquestionably the expression of pressure within or without the cord, and whether they be transitory or permanent depends altogether upon the nature of the cause. It has been said by some that an excessive collection of cerebrospinal fluid may be held responsible for the pressure symptoms. This seems to me possible but unlikely. I believe the most common cause is hemorrhage without the cord into the subarachnoid space or hemorrhage and edema within the cord; and, depending upon the extent, but more especially upon the seat of the hemorrhage, are the symptoms transitory or permanent. The effects of a moderate hemorrhage without the cord into the meshes of the arachnoid would hardly be more than temporary; the same might be said of a transitory edema within the cord. But hemorrhage within the cord may readily lead to permanent structural changes, so extensive as to cause a complete transverse lesion. The importance, therefore, of the avoidance of trauma and strict hemostasis is again emphasized.

Pneumonia or hypostatic congestion is a complication of cord lesions rather than of laminectomy *per se,* but it is mentioned at this time merely to suggest the propriety of elevating the patient's head and trunk as a prophylactic measure. This applies only to cases with paralysis of the respiratory muscles, as in cervicothoracic lesions.

The prevention of adhesions is a pertinent question. If for any reason the necessity of reopening the dural canal arise, the procedure will be devoid of difficulty, provided there are no intramembranous adhesions, and the converse of this may be stated in more forceful terms. The presence of adhesions is a very grievous obstacle to exploration. How to prevent them is, therefore, a vital question. To deny the tendency for them to form is to close one's eyes to the truth, and to account for their existence when reasonable precautions are taken is somewhat baffling. I have given much time and thought to this problem, and, excluding infection,

the possible causes of adhesions to my mind may be narrowed down to hemorrhage and trauma. As for hemorrhage, the deposition of the fibrin in the blood between the membranes in the course of the operation provides at once a means whereby a point or area of adhesion may be formed. On this account particularly must minute care be taken to protect the subdural sac from contamination with blood, and to this end bleeding should be controlled wherever possible before the dural sac is opened. But there will be more or less uncontrollable oozing to be provided for, and to protect the sac from this I have suggested the use of tampons of cotton laid one on either side of the dural incision, so that when the dural flaps are reflected with traction sutures, the cotton tampons will prevent the overflow of blood into the dural sac. Thus, it is a comparatively simple matter to prevent the deposition of fibrin within the sac when the source of hemorrhage is extradural. Not so, however, when the hemorrhage is subdural, since the necessities of the situation, the removal of tumors, the cutting of roots, will provoke more or less bleeding, the control of which will tax the resources of the operator.

The second source of adhesions is the exudate that may form in the membranes as a result of trauma or in the process of repair of the dural incision. The endothelial lining of the dura, like that of intima and peritoneum, is so sensitive to the insult of trauma that it demands the greatest respect.

The Laminectomized Spine.—There has been, and still is, a very prevalent belief—not among surgeons, however—that the removal of spines and laminae robs the patient of the ability to support the weight of the head or body in greater or less measure, and that after laminectomy the strength of the back is seriously impaired. This is an entire misconception of facts. Necessary as the spines, laminae or intraspinal ligaments might seem to be, it is surprising how little the removal of these structures interferes with the carriage of the body at rest and in motion. This general statement must be qualified in two particulars: first, when the structure of the vertebral bodies is tuberculous or the seat of a malignant tumor, the removal of spines and laminae may be a matter of some consequence and calls for some methods of artificial support. It has been suggested that under such circumstances the spinous processes, laminae and articular processes above and below the defect may be lashed together with strong silver wire. I have never had occasion to adopt this suggestion, practical as it seems, and would hesitate to do so because of the possible complications of wound repair. Theoretically, the demands for this method of giving greater security to the spine are not very great; if the indication be of malignant disease of the vertebral bodies, a spinal brace would answer the purpose quite as well for the time that remains until the patient becomes bedridden, and if the indication be of tuberculous spondylitis, the lesion itself would necessitate the use of a brace or

some other fixation appliance. Secondly, the restoration of function in the laminectomized spine will be influenced, not by the number of spines removed, but by their location. The only disability that has been brought to my attention was after the removal of the laminae of five lumbar vertebrae. One of my patients, a middle-aged man, suffered more or less discomfort in the form of pain on certain movements and a feeling of lack of support. Naturally there is more strain at the lumbosacral junction than elsewhere, not only because it is at the base of the spine and supports the entire body, but because this is the junction between a movable and a fixed point in the vertebral column, a point which of necessity is subjected to greater strain.

Leaving out of consideration, therefore, laminectomies at the lumbosacral junction and in the presence of softened vertebral bodies, we now have no hesitation in removing as many consecutive spines and laminae as may be required for thorough exploration or for adequate dealing with the lesion itself. The osteoplastic flap is not essential to the maintenance of function, but perfect apposition of the several musculo-aponeurotic layers in the closure of the wound plays a very important part.

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CHAPTER XVI

CHORDOTOMY

Chordotomy, a term coined to express an incision into the cord, has been recommended for the relief of various conditions: by Schüller as a substitute for Förster's operation, rhizotomy, in cases of gastric crises and spasticity, by Spiller in cases of unbearable pain in inoperable tumors of spine or cord, and by Krause and Taylor in cases of meningomyelitis.

Theoretically Schüller claimed for chordotomy, section of the posterior columns, certain advantages over rhizotomy in the treatment of spasticity, in that the former is a very much less formidable procedure and requires a comparatively small exposure: for spasticity of the upper extremity one cervical segment, and for spasticity of the lower extremity one thoracic segment. By this operation not only sensation but muscle tone as well is affected. One might protest against chordotomy because of the resulting anesthesia, but inasmuch as Förster has recently recommended section of all the posterior roots to a given extremity instead of, as originally, one in every three, the resulting anesthesia after rhizotomy and chordotomy would not differ materially. For spasticity of the lower extremities, Schüller proposed section of the posterior columns and cerebellar tracts at the level of the tenth thoracic segment, and for spasticity of all four extremities or one upper and one lower, section at the level of the fifth cervical segment. Although Schüller suggests that section of posterior columns will relieve spasticity, yet the physiology of this procedure is not convincing to me. It would seem that in order for this method to be effective the main reflex fibers from the posterior roots would have to run through a greater length of the posterior columns before passing into the gray matter than we have any reason to believe they do.

For the relief of gastric crises and for tabetic crises referred to the lower extremities, chordotomy has been proposed by Schüller, Förster and Exner. Rothmann does not approve of the operation for gastric crises because of the permanent loss of pain and temperature sense and because the pains might disappear spontaneously. Nonne referred to his experience in three cases of gastric crises with immediate relief in one, death in a second, and paraplegia in a third. At the suggestion of Förster, Tietze sectioned the anterolateral columns of the cord in a patient with unbearable pain in the left leg. Previously the sixth to the twelfth posterior thoracic roots had been cut for gastric crises. Because of the later involvement of the left leg, it was proposed to resect the lumbar

roots. The attempt was abandoned at the first operation and at the second operation it was found impossible because of adhesions; hence, it was decided to section the anterolateral columns. The pains in the left leg entirely disappeared. There was some analgesia of the left side up to the level of the nipple and a transient weakness in the bladder, but the operation fulfilled its purpose in the most satisfactory manner.

When for one cause or another the patient is subject to intense suffering, as in inoperable tumors involving the cord or cauda equina, Spiller in 1912 proposed the division of the anterolateral column of the spinal cord, leaving other portions of the cord intact so that paralyses of the limbs, bladder or rectum might be avoided. Spiller's recommendation was based upon the assumption that the fibers for pain were confined to one system within the spinal cord and that pain sensations could not be conveyed by other systems when the fibers usually employed for this purpose were destroyed. As a result of his investigations, Rothmann found that pain sensations were conducted through the anterior part of the lateral column and the work of Rivers and Head suggested the possibility of dividing the tracts for the conduction of pain with little damage to the rest of the cord function, except probably the involvement of the fibers of temperature sensation. These observations had been anticipated by the researches of Spiller in 1905 which localized the fibers for pain sense in the anterior columns and were confirmed later by the experiments of Cadwalader and Sweet, who, after dividing the anterolateral columns in the lower animals, produced definite loss of cutaneous sensation for pain and for extreme heat with pronounced ataxia, probably because Gowers' tract is in such close proximity to the anterolateral column. The temporary paralysis which has been observed in the experimental laboratory after section of the tracts for pain sensation as well as in the human subject is apparent rather than real. Cadwalader interprets the phenomenon as a profound disarrangement of the neuromuscular apparatus, together with impairment of cutaneous sensibility, causing a pseudoparalytic or true paralytic ataxia. The sensory impression which should pass through Gowers' tract had been cut off and, as the compensatory function of the remaining sensory tract was being established, the pseudoparalysis gradually disappeared.

The first operation of this character was carried out at Spiller's request by Martin, who, in a patient with an inoperable tumor involving cord and roots, divided the anterolateral column on either side. The patient was greatly relieved by the operation. Beer's patient was suffering from pains in the right lower extremity fifteen months after a hysterectomy for carcinoma of the cervix. Nothing was discovered on physical examination save a mass in the right pelvis, tenderness over the third and fourth lumbar spines, and sensory disturbance in the right lower extremity. To test the possibility of relief from the operation in contempla-

tion stovain was injected into the spinal cord, with complete temporary relief. After removal of the laminae of the ninth and tenth thoracic vertebrae, Beer sectioned the left anterolateral column of the cord. The incision began 2.5 mm. from the exit of the posterior root and was carried forward and to a depth of 2.5 mm. The relief obtained was striking, and the patient was able to walk about comfortably eleven days after the operation. There was a transitory paralysis of the right leg, complete loss of pain sensation, complete loss of perception of cold, though heat sensation was partly preserved, suggesting disassociation of heat and cold fibers. There were no trophic, vesical or rectal symptoms, and pain was entirely relieved. There was slight disturbance of touch sense and deep pressure, while sense of position in all points was very accurate. The operation in every way fulfilled its purpose. I have had occasion to apply this principle in three instances for the relief of pain and the results substantiated in the most gratifying way all that Spiller anticipated.

For the relief of unbearable pain in a patient with an inoperable sarcoma of the lumbar vertebra division of the anterolateral columns of the cord affords immediate relief.

My patient, a man, *aet.* 31 (File No. 33336), was referred to me by Dr. Alfred Stengel with a history of a tumor of the cord or cauda equina. An exploratory operation by my associate, Dr. George P. Müller, was carried out August 26, 1916, at which time the spinous processes and laminae of the eleventh and twelfth thoracic and first and second lumbar vertebrae were removed and the cord inspected with negative results. The symptoms continued, a second exploratory operation was decided upon, and, October 7, 1916, Dr. Müller and I removed the spinous processes and laminae of the third, fourth and fifth lumbar vertebrae. As we were about to remove the laminae of these vertebrae, a cavity was discovered on the left of the spine at about the level of the third lumbar vertebra. This cavity, the exact dimensions of which could not be determined, was filled with a mass of tissue resembling sarcoma. As much of it as possible was removed and two tubes of radium introduced before the operation was concluded. The radium was removed twenty-four hours after the operation. The patient was placed upon Coley's fluid and, while pain was somewhat diminished by the operation, it was still so intense that even with liberal doses of morphin hypodermatically given the patient spent sleepless nights and suffered more or less constantly. After conference with Dr. Spiller, it was decided to attempt to relieve the insufferable pain by a division of the anterolateral columns of the cord. Accordingly, on November 11, 1916, this operation was performed. After removal of the spinous processes and laminae of the ninth and tenth thoracic vertebrae and rotating the cord by traction upon the denticulate ligament, the anterolateral columns were divided with a cataract knife, representing a section about three millimeters long and two and one-half millimeters deep. Division of these columns was made by transfixion, the knife being introduced at a point on the surface of the cord two and one-half millimeters anterior to the point at which the posterior root emerged and the columns divided. Before these manipulations were begun a pledget of cotton saturated with four per cent stovain solution was spread out over the surface of the cord immediately above the level of the section of the column. Immediately after the latter was applied the patient's

pulse became weak and rather difficult to count; the pupils were contracted. There was, however, no cyanosis. The patient was given 1 c.c. of pituitrin hypodermatically and his condition gradually improved until at the conclusion of the operation there was no cause for alarm. As a result of the operation it was possible immediately to discontinue the use of morphin, upon which the patient had been dependent, receiving as much as two grains in the twenty-four hours. From the time of the operation until his discharge from the hospital, five weeks later, the patient was entirely free from pain. An examination five days after the operation showed absence of pain sensation throughout both lower extremities with preservation, although diminution, of tactile sensation. Thermal sensation was diminished in the thighs anteriorly, but totally absent below the level of the knees. Tactile sensation was preserved throughout both lower extremities; in other words, examination revealed a total loss of pain and practically all thermal sense, with partial preservation of tactile sensation, below and including the area supplied by the first lumbar segment. So far as the effects of the operation were concerned the relief afforded the patient seemed more than to justify the temporary discomforts attending the preparation for and performance of the operation.

With an entirely different object in view Krause and Taylor have practiced chordotomy. In certain cases of meningomyelitis both Krause

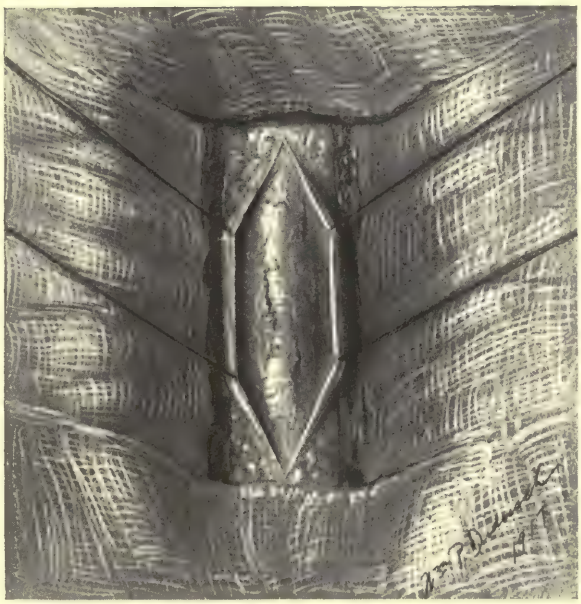

FIG. 375.—CHORDOTOMY.
The cord is exposed by removal of two spinous processes and laminae and a longitudinal incision in the dura.

and Taylor recommended a decompressive laminectomy together with a longitudinal incision in the cord. The latter is made to one side of the median line in the posterior column three centimeters in length and two millimeters in depth and is believed to be of value in those cases in which

there is marked infiltration and swelling of the cord. Theoretically, the incision facilitates drainage of the inflammatory exudate and encourages the process of resolution. Whatever may be the effect of chordotomy alone, the combination of chordotomy and decompression seemed to diminish the period of convalescence and to lead to a greater restoration of function than in those cases treated expectantly. In three out of Taylor's four cases the improvement was prompt and extraordinary, considering the degree of disability and the character of the illness.[1]

This chapter would not be complete without reference to the experimental work of Allen (*vide* Chapter VI, p. 398), who by his experiments achieved the most extraordinary results after spinal cord traumas by a median longitudinal incision of the cord. Following injuries to the cord which, in the natural course of events, would have led to complete loss of function, a chordotomy was followed by almost complete recovery from both motor and sensory disturbances. Unfortunately the application to human surgery of this original proposal has not as yet achieved the desired result, chiefly, I believe, because the method has not been applied, as Allen insisted, soon enough after the injury. My own experience has been limited to two cases and in only one of these was the operation performed within a time sufficiently soon after the accident to be considered ideal. The results in one of these cases were negative, though life was preserved. In the other there was a very evident amelioration of conditions. I feel, however, I must have more experience in order to form an adequate opinion of what may be expected from this procedure. But under appropriate circumstances, the proposed treatment meets with my unqualified approval.

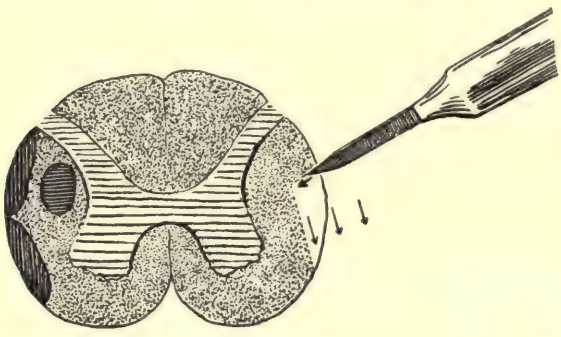

FIG. 376.—DIAGRAMMATIC REPRESENTATION OF SECTION OF AN ANTEROLATERAL COLUMN OF THE CORD, SHOWING THE POINT AT WHICH THE CATARACT KNIFE IS INTRODUCED AND THE DIRECTION IN WHICH THE INCISION IS MADE.

The shaded areas on the opposite side of the cord represent the anterolateral column, the direct cerebellar tract and the crossed pyramidal tract.

Technic.—The performance of chordotomy presupposes familiarity with the structures of the cord and the anatomical relations of the various tracts. Whether the chordotomy contemplates section of the anterolateral columns, the cerebellar tracts, the posterior columns or a median longi-

[1] These cases are referred to more in detail in the chapter on Decompressive Laminectomy, p. 921.

tudinal incision, a laminectomy is implied and at least two spinous processes and laminae should be removed (Fig. 375). After the dural sac is opened, the tracts may be divided in one of two ways—either by a cataract knife or by needle and suture. For the longitudinal incision, a cataract knife alone is feasible, but for division of the tracts, either knife or thread may be used. Whichever method be adopted, the cord must be fixed, and this is best accomplished by grasping the denticulate ligament with mosquito forceps. A small curved needle armed with fine silk is then

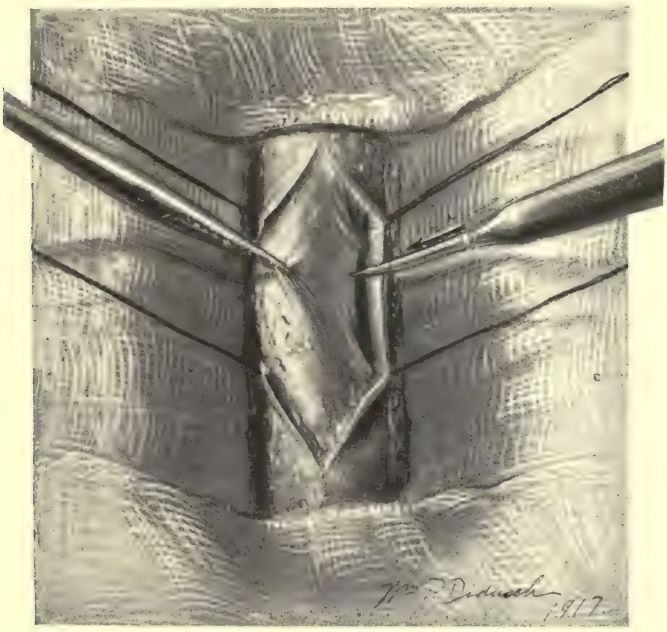

FIG. 377.—CHORDOTOMY.

The denticulate ligament is grasped with mosquito forceps, the cord is rotated sufficiently to expose the lateral aspect and the cataract knife is about to be introduced into the cord at a point 2.5 mm. anterior to the line of emergence of the posterior root.

introduced in such a way as to include the desired tract or tracts, and with a gentle sawing motion the tract from within outward is divided. If with the cataract knife, the cord is transfixed at the base of the tract and the latter is cut from within outward. Following section of the cord there will be a moderate amount of oozing, but so little as to be negligible (Figs. 376 and 377).

The gross topographical relations of the various tracts may be seen in Fig. 376. The posterior columns of the lower thoracic cord are triangular in shape, three and five-tenths millimeters at their base and about four and five-tenths millimeters in depth. The anterolateral columns are about two millimeters in depth and two and five-tenths millimeters in

length, and the posterior limits of the column are about two and five-tenths to three millimeters anterior to the point at which the posterior root emerges from the cord.

The level at which the column should be divided will depend upon the purpose for which the operation is to be performed. In a few operations in which the anterolateral columns have been divided for the relief of pain in the lower extremities, the division has been made at the level of the tenth thoracic vertebra or the ninth thoracic segment. I believe, however, that better results would be obtained if a higher level—the fourth, fifth or sixth thoracic segment—were selected. This level would be appropriate, not only for the relief of pain in the lower extremity, but for the relief of gastric crises.

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CHAPTER XVII

DECOMPRESSIVE LAMINECTOMY

As an operation for the relief of pressure upon the spinal cord, decompressive laminectomy may be said to be analogous to that for the relief of intracranial pressure. In many particulars the analogy is quite close; there are the same structures to be considered, the unyielding encasement, the dense dural envelope, the excess of cerebrospinal fluid, the pathological lesion whatever it be, tumor, hemorrhage, infection or fracture. On the other hand, unless the dura be freely incised, the opportunity for the relief of pressure is not so great in spinal as in cerebral lesions where the subtemporal decompression implies a crucial incision in the dura. Decompressive laminectomy, however, has not received the same recognition as the corresponding operation upon the cranium, and yet there are certain lesions in which its merit should be acknowledged. Such, for example, are tuberculous spondylitis, inoperable tumors, deformities or displacements following trauma and a group of diversified diseases, including syphilis of the cord, multiple sclerosis and meningomyelitis, in which latter condition, in some unaccountable way, a decompressive laminectomy has been followed by considerable amelioration in some instances and in others by almost complete recovery.

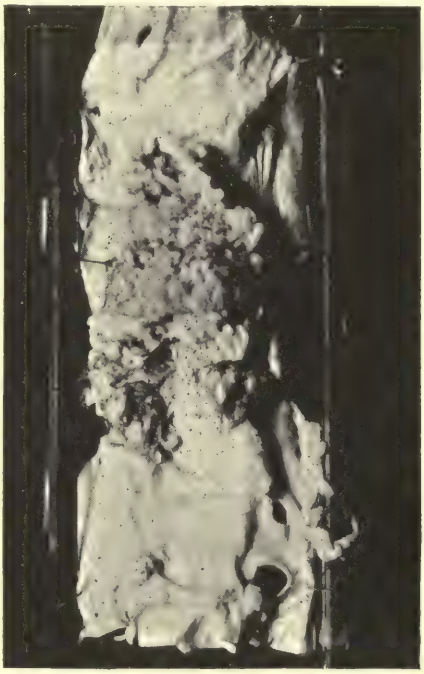

FIG. 378.—TUBERCULOUS CARIES OF THE VERTEBRAE, WITH INVOLVEMENT OF THE DURA. (Courtesy of Dr. William G. Spiller.)

There are three complications or sequelae of **tuberculous spondylitis** that give rise to pressure symptoms that may be relieved by surgical intervention: pressure upon the cord from angulation, pressure upon the cord by a tuberculous exudate, granulation tissue or pus (Fig. 378), and pressure from a displaced sequestrum. These indications for operative

intervention should be undisputed, and it is unfortunate that in the past the practice of surgeons should have been so conservative. If the operation is to be performed at all, it should be done before the function of the motor tracts has been entirely abolished. In a recent case upon which I operated there had been symptoms of cord pressure for fourteen months, and at the time of my first examination there was marked spasticity and the patient was unable to stand without support. The patient had been complaining also of some pain in the right leg and of muscular twitchings in both legs. The diagnosis was based upon a well-developed kyphosis and upon the x-ray examination. A decompressive laminectomy was planned, but before the arches of the laminae were removed there escaped from a communication with the spinal canal 20 c.c. of tuberculous pus. At this stage the operation was discontinued, with a view to completing it at a later sitting. The wound was left open and tamponed with iodoform gauze. Following this operation there was gradual improvement, and six months later the paraplegia and spasticity had entirely disappeared and the patient was able to walk without any hindrance. The advantage of early operation is illustrated in a case of Hildebrand's, who found, only four and one-half weeks after the beginning of cord symptoms, a mass of granulation tissue the size of a walnut. Hildebrand has operated upon ten cases of tuberculous spondylitis: in two the cord symptoms were entirely relieved, in four there was moderate improvement, and the remainder were uninfluenced.

Among the larger series of cases of Pott's disease which have been operated upon may be mentioned Chipault's collection of 101 cases and Lloyd's collection of 154 cases, including fifteen patients which he operated upon himself. Lloyd urged the importance of operating before other organs were involved and before the degeneration of the cord became so far advanced that recovery was out of the question. Especially adapted to the operation are those cases in which the posterior rather than the anterior aspects of the cord are involved, because the lesion is more accessible. In his operative experience in fifteen cases he found the cause was usually due to tuberculous granulation tissue rather than to bony pressure. In his statistical study of the results of 128 available cases the mortality was 16.45 per cent. This higher mortality rate may be ascribed in part to the fact that he included many cases which really should have been regarded as inoperable because of the existence of profound toxemia or of tuberculosis of other organs, so that death was due rather to complications than to the operation itself. As one would expect, the mortality was higher for the cervical than for the lower regions of the cord, being 27.77 per cent in the cervical region, as compared with 15.54 per cent in the thoracic region. In 128 cases subjected to analysis, 37, or 28 per cent, recovered from the effects of the operation; 16, or 12.5 per cent, were improved; and 18, or 14.06 per cent, were unimproved.

To what to attribute improvement in cases without any physical evidence of pressure either within or without the dura is a difficult matter. In his observation in a case of tuberculous spondylitis of the cervical vertebrae, in which for decompressive purposes the laminae of the fourth, fifth and sixth cervical vertebrae were removed, Corner assumes, as a cause of pressure, obstruction in the lymphatics. In the case under observation neither within nor without the dura was there any evidence of direct pressure upon the cord, and yet the operation was followed by return of power to the limbs and by disappearance of spasticity. The incision in the spinal membranes was not closed, in order to leave a large communication between the subarachnoid and epidural spaces.

In certain instances I have found in the presence of tuberculous spondylitis a layer of dense connective tissue surrounding the cord, which I have regarded as the eventual organization of the tuberculous exudate. In one case Mendler found a mass of dense tissue of bony hardness united to the laminae and compressing the cord. The arches of the second, third, fourth and fifth thoracic vertebrae were removed and for a distance of 3 cm. the cord was found flattened to one-half its normal diameter. There followed a slow but progressive recovery of bladder and rectal control, and two years after the operation the paralysis of the lower extremities had disappeared.

In the event of displacement of fragments, following isolated **fractures or dislocations,** a laminectomy with the consequent relief of pressure will favor the restoration of function. On one occasion I operated upon a patient four weeks after a fracture of the arches of the second, third and fourth lumbar vertebrae. There was no disturbance of sensation or of the bladder or rectum, but the interference with the movements of the lower extremities was so pronounced that the patient was bedridden. The arches of the second, third and fourth vertebrae were removed and within a few weeks there was gradual return of power, and at his discharge from the hospital, six months after the operation, the patient could walk the length of the ward without assistance. Likewise after dislocation a laminectomy may have the most beneficent influence. Take, for example, the following case of dislocation of the first lumbar vertebra. Immediately after the accident there was almost complete loss of motion in both lower extremities, anesthesia of the genitals and inner surface of the thighs, with complete paralysis of the bladder and loss of rectal control. In the course of a few months the patient regained sufficient power in the legs to walk a few steps with assistance, but he had no rectal control, and had to be catheterized. Johnson removed the spinous processes and laminae of the last thoracic and of the first and second lumbar vertebrae. The arch of the last thoracic vertebra was pressing upon the dura and a bony ridge could be felt pressing on the anterior surface of the cord, which appeared to be the upper border of the body of the first

lumbar vertebra. The dura was under tension and the cord was flattened. Within a week of the operation the patient could urinate voluntarily, and nine months later he had regained complete control of bladder and rectum and recovered sufficient power in his limbs to resume his occupation.

Inoperable tumors of the cord may be included among the lesions for which I have practiced decompressive laminectomy. As a rule in these cases, accompanying the motor disturbances, there is the excruciating pain of root pressure or infiltration and the operation should include division of the posterior roots. This additional procedure adds little to the gravity of the operation and much to the comfort of the patient.

Further consideration of the indications for decompressive laminectomy leads us into a speculative field, where in a variety of lesions, some of them obscure in origin and some of them uninterpreted even when exposed on the operating table, some of them even without evidence of pressure, a simple laminectomy has resulted in very striking improvement, even complete recovery. Included in this group are meningomyelitis, spinal syphilis, multiple sclerosis and cases simulating, in their clinical syndrome, tumors, but without any demonstrable lesion found at the operation. As in many instances and in most of the conditions resort has been had to surgical therapy purely upon an empirical basis, up to the present time the explanations that have been offered to account for improvement are wholly hypothetical. It remains only briefly to review the bare clinical facts without comment. It may be that with the accumulative experience of the next few years we may speak more definitely upon this absorbing subject, to present precise indications for operative undertaking, to explain the *modus operandi* of the effects of the operation and to prognosticate with reasonable accuracy the results.

The first operation for the relief of **meningomyelitis** was recorded by Krause in 1911. His patient, a male, 30 years of age, had enjoyed good health until his present illness, which began with severe neuralgic pains in the lower section of the trunk, affecting first the right hip and later both. A month later the pains had ceased, but there appeared some weakness in the left lower extremity. This weakness became more pronounced and in the course of the next six months the pains recurred, this time more marked on the right side and localized to both knees. At this stage catheterization became necessary and soon there was evidence of diminished sensation in the lower extremities. In rapid succession following the loss of vesical control there was fecal incontinence, girdle pains at the level of the umbilicus, violent attacks of pain in the back and sacrum and superficial decubitus. The patient was examined in consultation by Oppenheim, who gave it as his opinion that the nature of the trouble was indistinct and problematical, that the severity of the disease and its resistance to antisyphilitic treatment indicated an exploratory laminectomy. The operation was resorted to and consisted in the removal of the

spinous processes of the eighth and ninth thoracic vertebrae and the arches of the ninth and tenth thoracic vertebrae. Upon opening the dural sac a considerable quantity of fluid escaped and a troublesome venous hemorrhage ensued from separation of isolated adhesions between the dura and the arachnoid. The cord itself disclosed a spindle-shaped swelling, the lateral aspects of which presented a gravish blue discoloration and upon the surface a jelly-like appearance. The operation was concluded by closure of the musculocutaneous structures without closure of the dura. The final report upon the patient was made about two years after the operation, in which improvement was noted in certain particulars, more especially in the relief of the intolerable pain, in partial restoration of sensation and in return of power to the sphincters.

The essential features in a group of four additional cases under the care of Taylor and Stephenson were analogous to those in Krause's case. Following exposure to cold or trauma, the onset was characterized by severe neuralgic pains referred to a definite cord level; after remissions with exacerbations there were motor disturbances, loss of sphincter control and other symptoms suggestive of a transverse cord lesion, the level of which was fairly definitely indicated. The cord itself appeared swollen and congested, sometimes filling the canal, sometimes devoid of pulsation. In one of their cases there was no improvement, and the patient died on the twenty-fourth day. In the remaining cases there was marked improvement; the pains and objective sensory disturbances practically disappeared within four to eleven days and sphincteric control returned soon after that, and in one case motor power returned on the eighth day and on the sixteenth day the patient was able to walk. Two cases were still under observation at the time of the report.

The surgical treatment of meningomyelitis involves exposure of the cord, possibly a longitudinal median incision in the cord, should the latter be conspicuously swollen, and closure of the wound. The results of spinal decompression in meningomyelitis have, in some cases, been surprisingly good: the period of convalescence is shortened and the function of the cord is restored more nearly to normal, so that the patient from a helpless state of spastic paraplegia resumes an active calling. Theoretically, the improvement that follows this operation may be attributed to a more rapid absorption of the inflammatory exudate and to the restoration of the circulation to the affected regions of the cord.

Anent the question of decompressive laminectomy, Elsberg and Bailey record the peculiar and unaccountable influence of "laminectomy with simple exposure of the cord" in certain lesions. The effect of this procedure was not at all in the relief of pressure, since most of their cases gave no evidence of increased pressure, nor was any demonstrable lesion of the cord revealed at operation. In **multiple sclerosis** and **syphilitic disease** of the cord there were observed symptomatic changes chiefly in

the reflexes and in spasticity, but usually the changes were only of transitory duration. The pathological reflexes gave way to the normal, and certain degrees of spasticity were favorably modified. A striking example of the effect of laminectomy *per se* may be cited from the experience of Beckman, who removed the arches of the fifth, sixth, seventh and eighth thoracic vertebrae from an adult who was believed to have a spinal tumor. Two years and seven months after the operation the patient was absolutely free from pain, had regained normal strength in the thighs and legs and was able to engage in all sorts of activities, including horseback riding.

The effect of a decompressive laminectomy upon a peculiar and an unexplained pathological condition, **periostitis** of the fifth and sixth thoracic vertebrae and a definite **pachymeningitis,** was very striking in a patient operated upon by Lewis. Before the operation there was a well-developed spastic paraplegia with loss of sensation for pain and touch and loss of motion. Sensation began to return within forty-eight hours and motion within ten days. Improvement continued, and four years after the operation recovery was complete. There was no evidence either of tuberculosis or syphilis as the underlying cause. There appears, however, to be no logical explanation for the effect of the operation upon the function of the cord, and without such it is impossible to specify under what conditions the operation would be considered justifiable. The subject is altogether vague, and until further observations are made the operation cannot be placed in the category of accepted surgical procedures.

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